Power Measurement Lab

Microwave Measurements

Agilent Technologies

The lab to teach you the basics of how to make accurate power measurements with a broadband scalar measurement system.

Overview

- **Introduction to the equipment**
- **Part 1: Calibrate Power Meter and Validate Signal Generator Outputs**
- **Part 2: Measure Insertion Loss of one 75Ω Cable**
- **Part 3: Measure the Insertion Loss of a Second Cable**
- **Group Discussion**

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This lab will be composed of three primary sections. We will be using the E4418A Power Meter with the HP8481A Power Sensor to make our measurements. In the Following sections we will explore:

1: Power flatness of a signal generator across a frequency band of interest. Using the accuracy of a fully calibrated power meter, the calibration of the signal generator will be verified and correction factors generated.

2: The insertion loss of a 75Ω piece of cable will be measured and the uncertainties of the measurement will be explored.

3: We will add a second piece of 75Ω cable to our measurement and further explore our results and uncertainties.

Intro to the Equipment:
HP 8481A Power Sensor

- The HP8481A is general purpose power sensor, here are some of the specs
- 10MHz - 18GHz frequency range
- 1mW to 100mW power measurement range (-30dBm to + 20dBm)
- Maximum power 300mW continuous, 15W peak (30W/msec pulse)
- N male; 50 ohm connector.
- VSWR <= 1.10:1 50MHz - 2GHz

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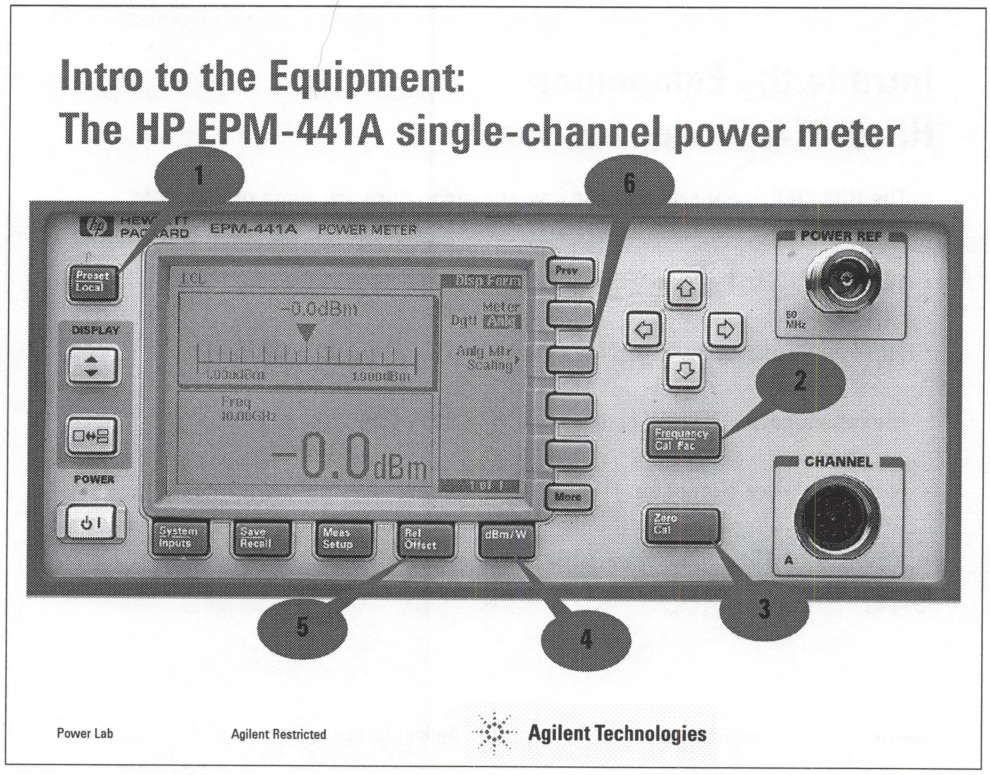
In this lab we shall use the HP8481A thermocouple power sensor attached to an EPM Series power meter. Above are some specifications for the power sensor. Take note when using power meter heads of the power ratings, they can be damaged quite easily. In this case the head can handle up to +20 dBm, so we should be just fine.

Note: The power meter uses a very stable 50 MHz CW at a power level of 0 dBm for the calibration power reference.



This is the EPM Series Power Meter used for the purposes of this lab. Note the locations of several instrument controls which we will be using.

1: [Preset/Local]	Presets the power meter to a known factory state
2: [Frequency/ Cal Fac]	Use this to change the cal factor and the freq of the internal source
3: [Zero/Cal]	Takes you into the calibration menus
4: [dBm/W]	Toggles the display from Log to Linear format
5: [Rel/Offset]	This provides access to the 'Rel' function menu
6: (Soft Keys)	These keys have various uses, their function can be read off of the display. In this case the top most soft key (below [Prev]) toggles the meter display from Digital to Analog.

*Note: Throughout this lab, the use of [square brackets] surrounding the title of a key indicates the key is a hardkey on the front panel of an instrument and the use of (round brackets) surrounding the title of a key indicates it can be found as a softkey.

Part 1:
Calibrate and zero the power meter

- **PRESET the power meter.**
- **Connect the power sensor to the Power Reference output port.**
- **ZERO the power meter.**
- **CALIBRATE the power meter.**
- **Verify the Ref calibration factor is 100%**
- **Verify the Cal using the internal power ref with the sensor connected.**

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Before measuring the the output power flatness of the Sig Gen. we must calibrate our power meter and power sensor. Typically, before performing the calibration a cal factor would have to be entered to accommodate for the frequency range where the measurement is being made. In this case the measurements will all be at frequencies much less than 1 GHz, therefore a cal factor of 100% should be used. Follow these steps to zero/calibrate the meter:

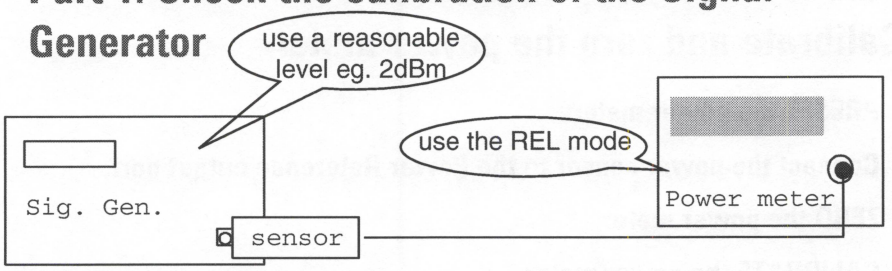
•Preset:	Press the green [Preset/Local] key
•Plumb:	Connect the sensor to the POWER REF port*
•Zero:	Press [Zero/Cal], then press (Zero) and wait for completion
•Cal:	Press (Cal) and wait for completion
•Verify:	Turn the POWER REF on by pressing (Power Ref On Off) so it is on and see that the measurement is 0 dBm.

Before proceeding with the measurement toggle the dBm/mW to view the display in both linear and log format (mWatts and dBm respectively.)

If your measurement of the Power Ref was not exactly 0 then try redoing the above procedure. If that does not work an adjustment to the Cal Factor may be in order. To do this, press [Frequency/ Cal Fac], then press (Cal Fac 100%) and use the up and down arrow keys to select a cal factor number. Once one has been selected press the (%) key to enter the value and then recheck your calibration. Note: This may be an iterative process.

**The power meter is smart and will turn on and off the power ref. appropriately during a calibrate and zero cycle. Pay attention to the green LED indicator on the top left side of the Power Ref port to verify this.*

Part 1: Check the calibration of the Signal Generator



Freq (MHz)	Relative Power (dB)
160	0 2.52
170	~~.03~~ .01
180	2.55 ~~.03~~ .03
190	-.03
200	2.46 -.06
210	-.08
220	2.50 -.02
230	-.01
240	2.49 -.03

Normalize (Rel) at 160 MHz

This table provides the flatness correction factors to use in the proceeding measurements.

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One of the specifications of a *signal generator* is the uncertainty of the output power setting. This is important because a signal generator is often used as a standard in making measurements related to power. For example, receiver sensitivity measurements depend on the calibration of the input signal level and the associated uncertainties. To check the flatness of the power output across a frequency spectrum of interest a power meter would be used. The 'Rel' function simplifies this measurement greatly.

•Set the frequency and choose a reasonable power output for the Sig Gen other than 0 dBm so 'Rel' use can be explored.

•Use REL mode on power meter: Press [Rel/Offset], then press (Rel.)

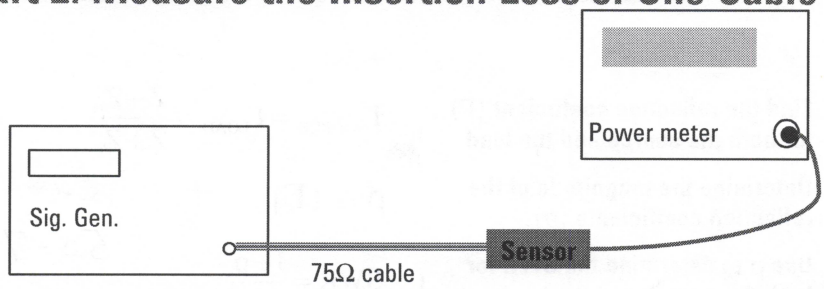
This will set the current power level at 0 and turn on the Rel function so all other measurements will be relative to this power level with the Sig Gen at 160 MHz.

•Take additional measurements at the frequencies listed in the table above and document your results.

Do you notice any trends in these measurements?

Note: The power meter is used to calibrate the signal generator. The display of power on the signal generator is an indicator of the approximate power level being output and ***NOT*** a power measurement.

Part 2: Measure the Insertion Loss of One Cable



	Freq (MHz)	160	180	200	220	240
M	Reative Power (dB)	-.21 2.31	-.29 2.28	1.36	1.78	2.19
C	Correction (dB)	2.52	2.55 -.29	2.46	2.50	2.49
L	Insertion Loss (dB)	.21	+.33	1.1	.72	.30

Insertion Loss = L = -(M-C) ***Signs are Very Important!***

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2.55
2.28
-.33

2.46
1.36
1.10

2.50
1.78
.72

The next step is to measure the insertion loss of a 75Ω piece of coax. The power meter has already been zeroed and calibrated and the Sig. Gen has been characterized, so the only thing left to do is make some measurements.

The 75Ω cable should be inserted between the Power Sensor and the Sig. Gen output with the appropriate adaptors. Once the cable is in place take measurements at each of the frequencies listed above and record your results. A smaller set of frequencies has been chosen for this measurement in the interest of time.

The values that are measured with the cable in place should be placed in the first row, Relative Power, since these are the values being measured. The 'Correction' row should be filled in with the corresponding measurements taken when characterizing the Sig. Gen. At this point, any additional frequency measurements previously made for the Sig. Gen can be disregarded. Complete the necessary algebra to determine the most accurate measure of the insertion loss of the cable.

Part 2: Calculate the Source and Load Mismatch

- **Find the reflection coefficient (Γ) for both the source and the load**
- **Determine the magnitude of the reflection coefficients (ρ)**
- **Use ρ to determine the SWR for both the source and the load**

$$\Gamma_{SOURCE} = \Gamma_{LOAD} = \frac{Z - Z_0}{Z + Z_0}$$

$$\rho = |\Gamma|$$

$$SWR = \frac{1+\rho}{1-\rho}$$

Source - CBL

$$\frac{50-75}{50+75} \qquad \frac{-25}{125} = -\frac{1}{5}$$

SWR of Source	~~50~~ 1.5
SWR of Load	~~75~~ 1.5

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By using cable with a different characteristic impedance (75 Ω) compared against the Sig Gen and Power Meter (50 Ω) there is a source of mismatch error which produces uncertainty in the measurement. To determine how much uncertainty is generated the SWR needs to be found.

First, the reflection coefficient can be calculated for both the load and the source using the first equation above, presented in the Transmission Lines section of the course. The magnitude of this result is the value for ρ which can in turn be used to calculate the SWR. As can be seen in the upcoming slide, the SWR will provide the information necessary to determine the uncertainty in the measurement due to mismatch error. Use the characteristic impedances below to determine the two SWR values.

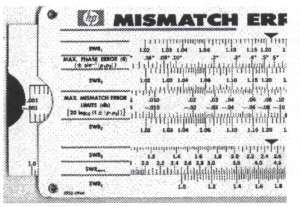
**When calculating the reflection coefficient (Γ), remember that Z_O for the particular calculation is dependant on your point of view. For example, to calculate the reflection coefficient (Γ) when looking into the cable from the source, Z_O is 50 Ω and Z_L is 75 Ω, likewise when looking out of the cable into the load (power meter sensor), Z_O is 75 Ω and Z_L is 50 Ω.*

$$Z_{O_{\text{SIG GEN and Power Meter}}} = 50\Omega$$

$$Z_{O_{\text{Cable}}} = 75\Omega$$

Part 2: Find the Measurement Uncertainty due to Mismatch Error

SWR1	1.5	Sliding scale
SWR2	1.5	Fixed Scale
Max mismatch error limits		$+x$ .34 $-y$ -.36



You can use the HP Reflectometer Slide Rule or calculate manually.....

$$x, y = 20\log_{10}(1 \pm |\rho 1 \rho 2|)$$

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There are two straight forward ways to determine how much uncertainty is being produced as a product of the mismatch error. The first method involves using the HP Reflectometer Slide Rule and the second is to directly apply the formula.

Due to the nature of Log and Linear scale conversions the amount of uncertainty added (x) or subtracted (y) typically will not be the same. In this case, however, the difference will be small and the two numbers can be assumed to be about the same for practical purposes.

To use the "Mismatch Error Limits" side of the Reflectometer, line up the first SWR on the sliding scale with the black upside down triangle on the top, in the middle of the slide rule. Next go down to the row marked "SWR 2" and read across until the second SWR value is found. Then the $+X$ and $-Y$ values can be read directly of the ruler.

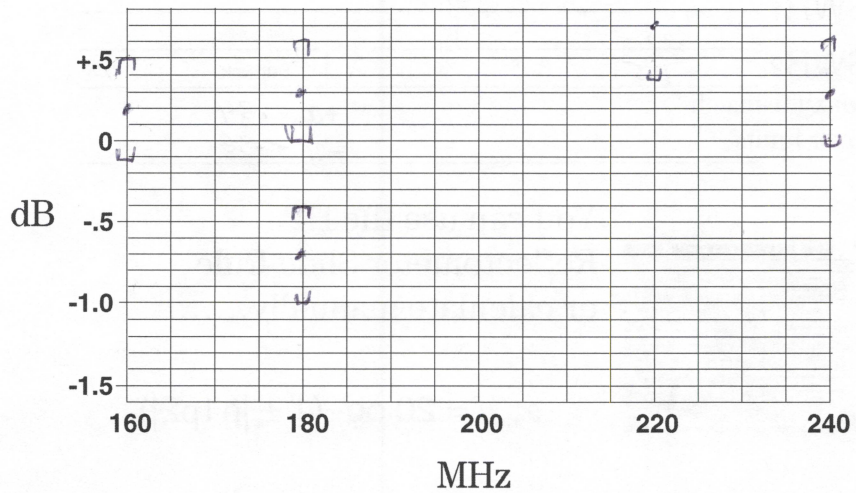
To use the formula mentioned above, simply place the values found for ρ into the equation and solve once with the + sign and solve again with the – sign for the upper and lower uncertainty values.

What did you get for the uncertainty values? (Hint: This is important for the work on the next page!

$+X$:_____

$-Y$:_____

Part 2: Plot the Insertion Loss with Uncertainty Limits



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Now that the uncertainties have been calculated, lets plot them on a chart and try to obtain a better understanding of what the numbers mean.

•Plot the points of the corrected insertion loss values on the graph at the corresponding frequencies of interest.

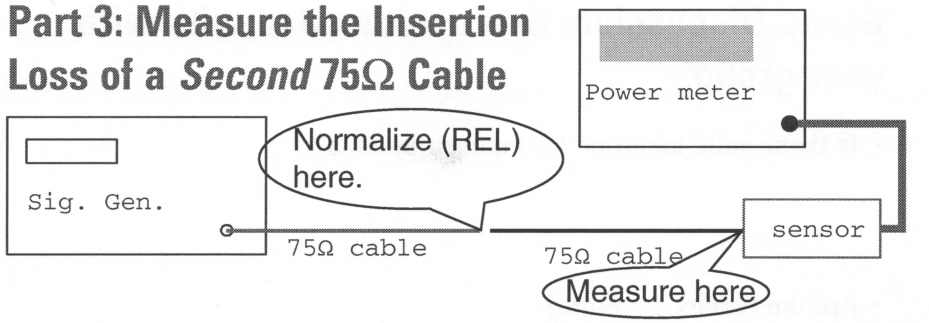
•Put brackets around the top and bottom of the points to represent the uncertainty like the example at the top of the page. The exact placement of the brackets will be determined by the calculated values for the uncertainties that were just found. Be careful when placing the brackets, pay attention to the vertical scale of the graph.

Is the mismatch uncertainty a large part of the measured value?

UNKNOWN

According to this graph, what is the largest value that could possibly be measured for the insertion ***LOSS*** of the cable? *i.e. What is the maximum value, including uncertainties, that a measurement could take?* 1.1/ 1.44

Part 3: Measure the Insertion Loss of a *Second* 75Ω Cable



Frequency	Insertion Measurement of Cable	λ	Cable Length (Approx)
60 MHz	1.97 -.16		6'
44 MHz	2.16 .03		6'
38 MHz	2.32 .18		6'

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The accuracy of a power measurement, especially when at low relative levels, can be degraded by reflections. This part of the experiment should emphasize this and the need to be aware of the uncertainties inherent in a given measurement.

The next step is to measure the insertion loss of a second cable while the first remains in the measurement system. Rather than measure with the new cable and subtract the values manually from the first cable why not "re-'Rel'" the power meter. With one 75Ω cable connecting the sensor to the Sig Gen, perform the same 'Rel' function performed earlier. Now when the second cable is inserted into the measurement system the measurement will be relative to the end of the first cable.

Now attach the second cable with the "bullet" f-f BNC adapter.

**Disregard that this bullet connector is 50Ω for this lab.*

Use the frequencies listed above for these measurements. They are different from the other set used, so the correction factors previously measured for the Sig. Gen are not valid here. They can be disregarded for the purposes of this measurement. Or can they?

Take some measurements and find out! After taking your measurements, calculate the wavelength (λ) using C = F λ, where F is the frequency and C is the speed of light ($3x10^8$ m/s.) Then approximate the length of the two cables together. Do you think there is some correlation here?

10

$\frac{3 \times 10^8 \text{ m/s}}{6 \times 10^7}$

Group Discussion: Discuss these results with your group.

- **Is these valid insertion loss measurements?**
- **Are the results accurate?**
- **Do the results fall within the expected uncertainty bounds?**

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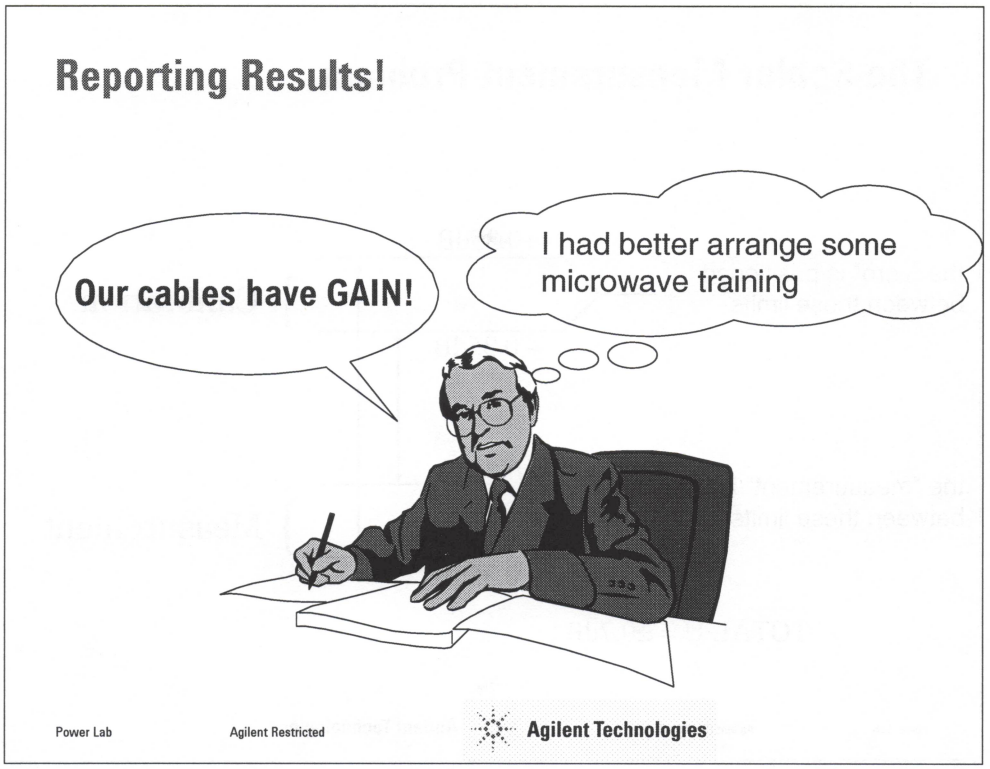
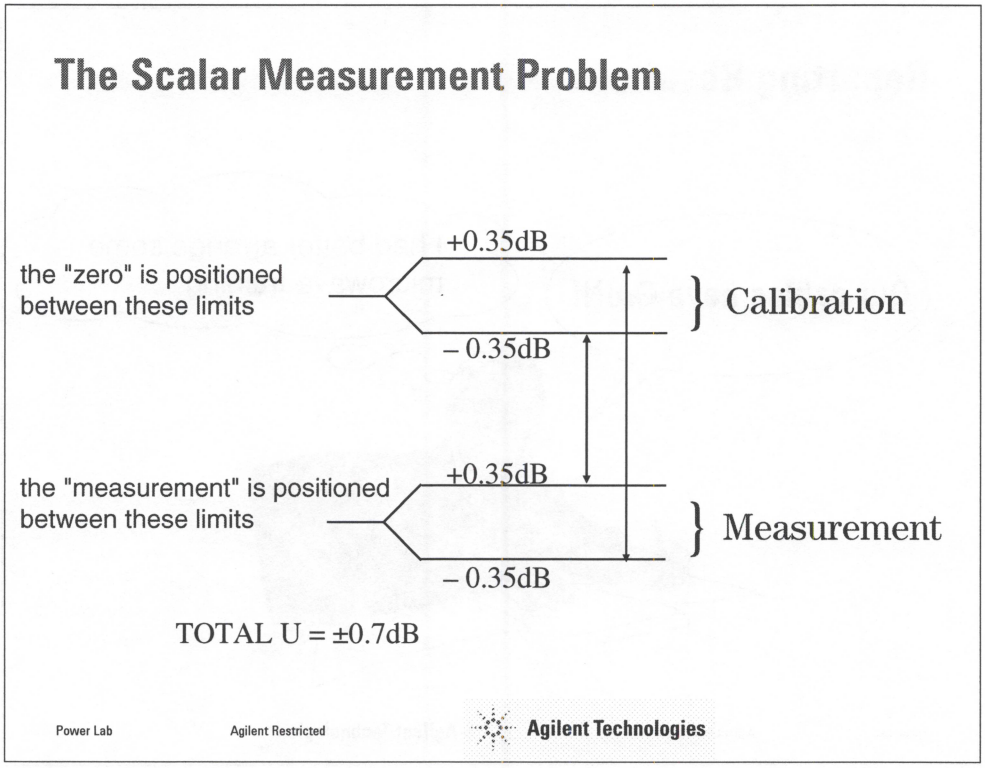
If you need extra space you can record your discussion results in this section:



It is physically impossible for a passive device like a cable to produce gain. Some may try to convince you otherwise, but you can rest assured they did not take careful account of the uncertainties in their measurements.

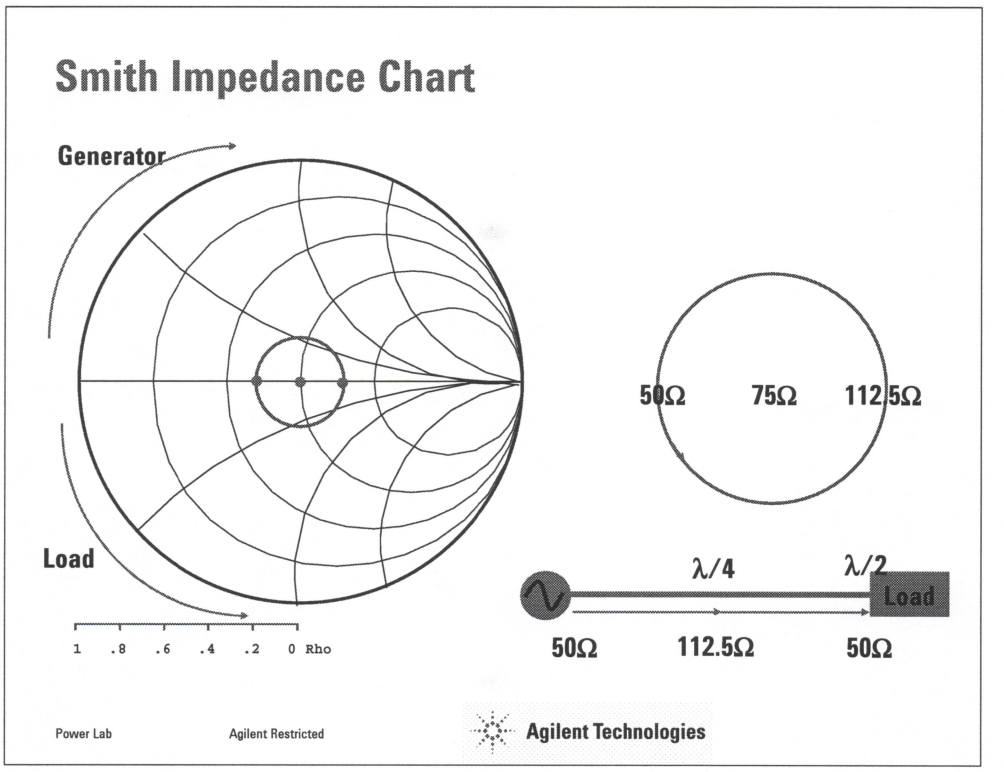
A main point to be shown by this exercise is that the measurements in the previous cases weren't BAD at all. They simply fell within a window of uncertainty which proved to be ridiculous when measuring a very low loss device like a cable. In the real world your work may not provide you with such extreme examples, but for that reason you must always keep the effects of mismatch and reflections in the back of your mind when making power measurements.



Both the calibration and measurement are subject to an uncertainty because the phase of the reflection coefficient is unknown and different between the two steps.

We set up this lab to demonstrate a point, that it is possible to measure a gain for a device that should have loss. How did we manage this? Well frequencies were chosen such that during the Cal stage the reflection coefficient (Γ_L) was 180° out of phase with the generator. This made power measurements look satisfactory. The second set of frequencies and the extra piece of cable measured during Part 3 placed the load an additional ¼ λ away form the generator, resulting in a much better match (50Ω versus 112.5Ω.) This made the 75Ω cable look like 50Ω to the power meter head, resulting in maximum power transfer to the Power sensor. By moving the phase by an additional ¼ λ the load was put in phase with the source, so the power measured was higher than what would be absorbed by a 75Ω load. This is a tool referred to as a ¼ wave transformer used frequently for RF matching network design.

NOTE: This cable ***gain*** showed up because we made a measurement of a device we expected to have a small loss close to 0dB. However if the device had been, for example, an attenuator we may have accepted the measurement and not bothered to assign an uncertainty to it.



Here is a Smith Chart which should help clarify some of the previous discussion.

The first normalizing step was made at one of the frequencies when the cable length was about one quarter of a wavelength. This meant that the 50Ω load was being driven from a 112Ω source impedance. When the second cable was added the electrical distance of the source to load was ½ λ, now the 50Ω load is being driven from a 50Ω impedance. The Smith chart above shows this well, in fact any low loss cable which is one half wavelength long acts as a one to one transformer, in this case the characteristic impedance of the cable is immaterial.

Many RF and microwave design books will explain this most useful tool. A source book is one by Phillip Smith himself "Electronic Applications of the Smith Chart" Noble Publishing Atlanta GA.

Power Measurement Basics labs

Lab 1—ACP and Channel Power

Set up a 2 GHz, -10dBm carrier.

QPSK modulation
Symbol Rate = 2 MHz
Alpha = 0.20

1. Using the Spectrum Analyzer's Channel Power capability, measure the channel power of this signal.

   In-Channel Power _____dBm

2. Measure the 1st adjacent channel power and calculate the adjacent-channel power ratio relative to the in-channel band power from #1.

   Adj. Channel Power _____dBm
   ACPR _____dB

Lab 2—Sensitivity

1. Measure the lowest detectable signal on the Power Meter by lowering Signal Power.
2. Measure the lowest detectable signal on the Spectrum Analyzer using RBW=100Hz.

Lab 3—Linear Scale

Measuring power out of signal generator (set to –20dBm) Power Meter in Watts:

1. Increase Sig. Gen. power until Power Meter reading doubles (x2). How many dB change is this?

X2 = _____dB

2. Increase Sig. Gen. power until Power Meter reading is 4 times higher. How many dB change is this?

X4 = _____dB

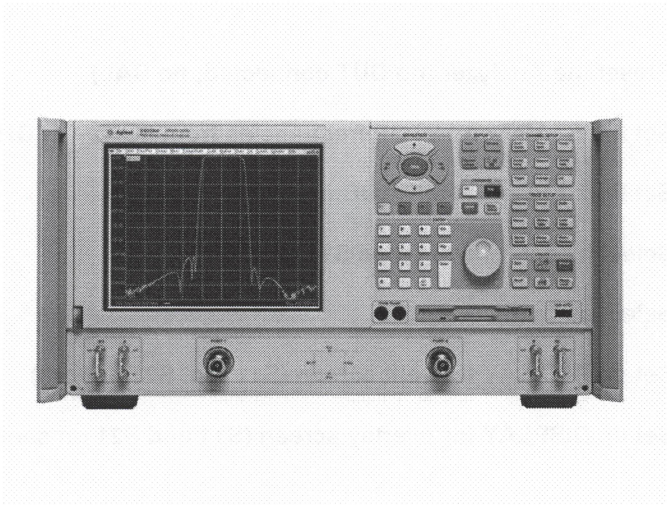
3. Increase Sig. Gen. power until Power Meter reading is 10 times higher. How many dB change is this?

X10 = _____dB

Lab 4—75 ohm Cable Measurement

(Follow procedures in the back of the class handout.)

Network Analysis Lab



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SLIDE 1

EXERCISE
Network Analyzer Set-up

1. Preset the Analyzer (no DUT connected; no CAL)
2. Set the START and STOP frequencies from 2GHz – 18GHZ
3. Set Port 1 POWER to –10dBm
4. Select measurement types S11 and S21
5. Select units (LOG MAG)
6. Set up DISPLAY for split screen (S11 top, S21 bottom)
7. Set up DISPLAY for overlay screen (S11 and S21 on same plot)

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SLIDE 2

EXERCISE
Smith Chart

1. **Preset the Analyzer (no CAL)**
2. **Set the START and STOP frequencies from 8.5GHz – 11GHZ**
3. **Measure S11 of a 3.5mm SHORT**
4. **View LOG MAG and Smith Chart**
5. **Repeat for 3.5mm OPEN and 3.5mm LOAD**

Where does the SHORT appear in the Smith Chart?
Where does the OPEN appear in the Smith Chart?
Where does the LOAD appear in the Smith Chart?

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SLIDE 3

EXERCISE
Coupler Directivity

1. Preset the Analyzer (no CAL)
2. Set the START and STOP frequencies within the range of the lab coupler
3. Connect Port 1 to Coupler INPUT and Port 2 to Coupled Arm
4. Connect a 50 ohm LOAD to Coupler OUTPUT (no reflections)
5. Measure S21 (COUPLING FACTOR)_____dB
6. Connect Port 1 to Coupler OUTPUT and Port 2 to Coupled Arm
7. Connect a 50 ohm LOAD to Coupler INPUT (no reflections)
8. Measure S21 (ISOLATION)_____dB
9. Calculate DIRECTIVITY = ISOLATION – COUPLING _____dB

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SLIDE 4

EXERCISE
Directivity Error Effects

1. Preset the Analyzer (no CAL)
2. Set the START and STOP frequencies over entire range of the lab filter
3. Connect Port 1 to Filter INPUT
4. Measure S11
5. View LOG MAG

Does the trace appear flat?
What causes the non-flatness?

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SLIDE 5

EXERCISE
SHORT Verification

1. Preset the Analyzer (no CAL)
2. Set the START and STOP frequencies from 2GHz – 2.5GHZ
3. Connect 3.5mm SHORT to Port 1
4. Measure S11
5. LOG MAG_____dB
6. PHASE _____degrees

What reflection do you expect to see?

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SLIDE 6

EXERCISE
THRU Verification

1. Preset the Analyzer (no CAL)
2. Set the START and STOP frequencies from 10GHz – 20GHZ
3. Connect a thru-cable between Port 1 and Port 2
4. Measure S21
5. LOG MAG_____dB
6. PHASE _____degrees

What transmission characteristics do you expect to see?

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SLIDE 7

EXERCISE
Display Set-ups

1. Preset Analyzer
2. Connect lab filter between Port 1 and Port 2
3. Set up START and STOP frequencies to match lab filter range
4. Measure S11, S22, and S21
5. Set up DISPLAY for S11, S21, S22 LOG MAG and S21 PHASE
6. Set up 4-Screen DISPLAY showing all measurements

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SLIDE 8

EXERCISE

Following the General Measurement Procedure but omitting calibration:

- Mission
  - Set up the network analyzer to measure the DUT
  - Measure S11 in dB (return loss)
  - Measure S21 in dB (insertion loss)
  - Display both measurements simultaneously
- Need to Know
  - Device Type (Filter, amplifier, etc.)
  - Start/Stop or Center/Span Frequencies
  - Stimulus Power Limitations

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SLIDE 9

EXERCISE
Electrical Delay and Group Delay

1. Preset the Analyzer (no CAL)
2. Set START/STOP frequencies to cover lab filter range
3. Connect lab filter between Port 1 and Port 2
4. Measure S21 PHASE
5. Flatten phase response by dialing in <Electrical Delay>
6. Measure S21 GROUP DELAY

If possible, also display S21 LOG MAG.
What does Electrical Delay tell us?

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SLIDE 10

EXERCISE
Markers

1. View S21 LogMag of the lab filter
2. Place a marker on the filter center frequency
3. Measure out-of-band rejection
4. Add S11 of lab filter to Network Analyzer and view LogMag
5. Place a marker at the filter center frequency and measure Return Loss
6. Set up 4-Screen DISPLAY showing
   S11 Log Mag
   S21 Log Mag
   S21 Phase
   S11 Smith Chart
7. Set up markers on all screens and couple markers together

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SLIDE 11

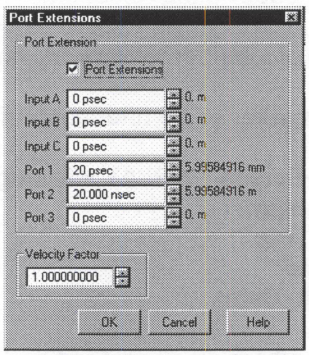
Exercise
--Port Extension

Set up S21 LogMag and Phase of cable or filter

View [Calibrate]→Port Extension dialog box

Change Port1 and Port2 values and view S21

What changes?*



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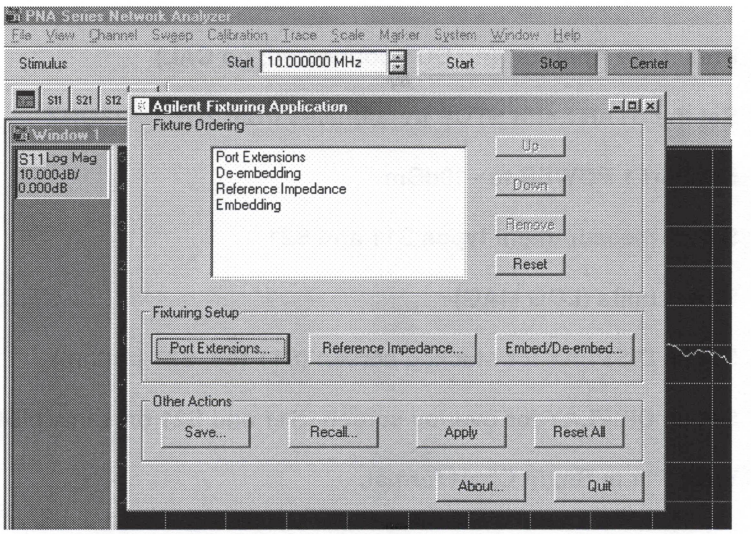
SLIDE 12

Under [Calibrate]→Port Extension, enter in port extension delay values as shown.

Exercise—Port Extension Fixturing Application



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SLIDE 13

To access the Fixturing Application, press the [Macro/Local] hard key (in the Utility section on the lower right of the PNA front panel) until "Fixturing" appears in the active entry menu.

Port Extensions can be added (as delays), with or without loss, at specific frequencies for each port. The reference impedance (R+jX) can also be modified for each measurement path or channel. Embedding or De-embedding of 2-port networks from each path/channel can be selected from stored .s2p (Touchstone format) files.

Embedding may be required to insert matching circuits, whereas de-embedding would be used to take out the effects of fixtures from a measurement.

EXERCISE
Network Analyzer Set-up

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3. Set Port 1 POWER to –10dBm
4. Select measurement types S11 and S21
5. Select units (LOG MAG)
6. Set up DISPLAY for stacked screen (S11 top, S21 bottom)
7. Set up DISPLAY for overlay screen (S11 and S21 on same plot)
8. View S11 in Smith Chart format.

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SLIDE 14

Exercise: Full 2-port Calibration

Mission:

- Set-up the VNA for a 2-port measurement of lab filter
- Perform a full 2-port calibration
- Verify the calibration
- Measure insertion loss (S21) and return loss (S11) of the DUT
- Compare corrected with uncorrected results

Need to Know:

- Connector Types of both ports of the DUT
- Start/Stop or Center/Span for testing the DUT
- Stimulus Power Limitations of the DUT

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SLIDE 15

Exercise
-Changing Sweep Speed

1. **Preset the VNA**
2. **Set up for S21 with IFBW = 10Hz (slow sweep time)**
3. **Connect DUT– long cable or filter—between Port1 and Port2**
4. **Perform a THRU Response CAL**
5. **Set SCALE to 1dB/div and save trace to memory**
6. **Display both memory and measurement on one screen**
7. **Increase sweep time by increasing IFBW**
8. **View the response. Has it changed?**
9. **What are the sweep times for each trace?**

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SLIDE 16

Connect either a long cable or filter between ports 1 and 2 of the Network Analyzer. Examine the sweep time by clicking [Sweep Setup]→Time.

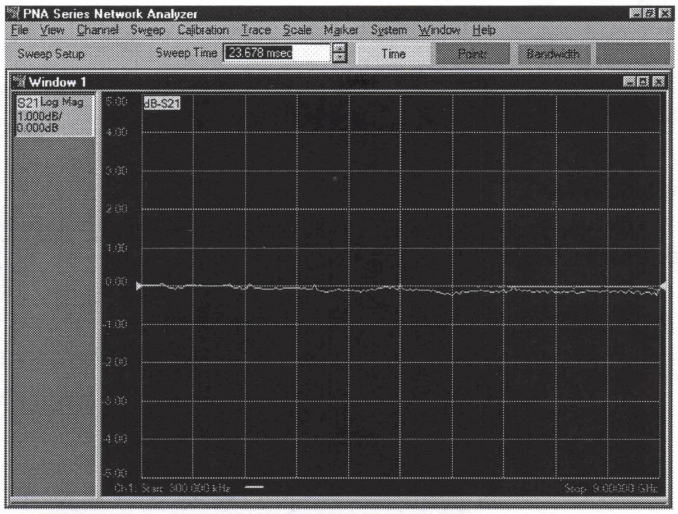
Example in the PNA:

With IFBW = 10Hz, Sweep Time = 17.7957 sec

Change IFBW to 1kHz. Sweep Time = 185.684msec.

Change IFBW to 10kHz. Sweep Time = 23.678msec.

Exercise (Cont.'d)
--Sweep Speed



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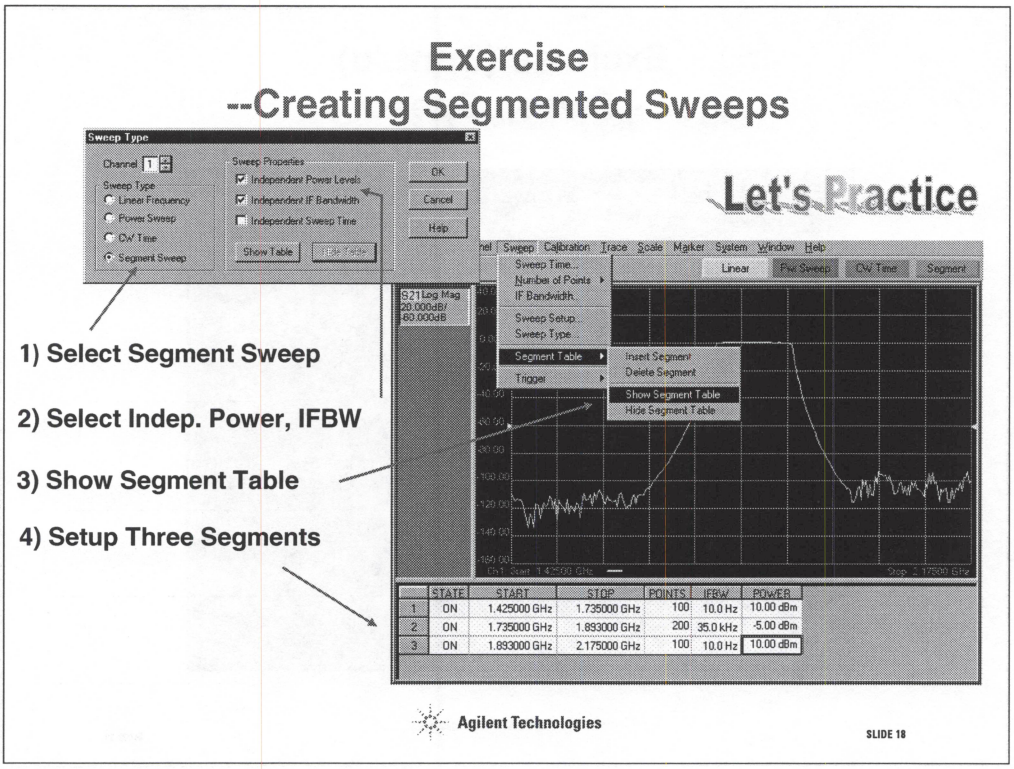
SLIDE 17



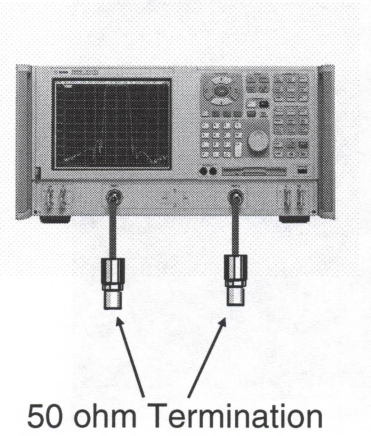
Let's practice setting up a segmented sweep by following the steps outlined above. You can set up the segments as they are shown above. Note that the second segment has twice the number of points as the other two segments. In most cases when you are measuring a filter, you'll find that you need more resolution in the passband to be able to accurately find the peak-to-peak ripple. Down in the noise of the stop bands, resolution is not important, but dynamic range is. That is why you see a smaller IF BW. You will note a power change as well in the different segments. This is not necessary for your configuration. If you were using the network analyzer in direct-receiver access mode, have reversed the port-two coupler, or are measuring an amplifier/filter combination, then you would need to drop the power in the various segments. For a passive device using the standard network analyzer configuration, you would want to use the maximum amount of power for the whole sweep.

EXERCISE:

Set up the segmented sweep as above, using the stop- and pass-band frequencies of the lab filter.

Lab Exercise : Dynamic Range

Measure Receiver Noise Floor with Pads on Test Ports
Compare to Specs



Measure S21
Response + Isolation Cal
Use 10 Hz IFBW / No Averaging
Terminate the Test Ports
Measure Noise Floor

Receiver noise floor[a]	
300 kHz to 1 MHz[c]	
10 Hz IF bandwidth	≤ –130 dBm
3 kHz IF bandwidth	≤ –110 dBm
1 MHz to 3 GHz[c]	
10 Hz IF bandwidth	≤ –133 dBm
3 kHz IF bandwidth	≤ –113 dBm
3 GHz to 9 GHz	
10 Hz IF bandwidth	≤ –123 dBm
3 kHz IF bandwidth	≤ –103 dBm

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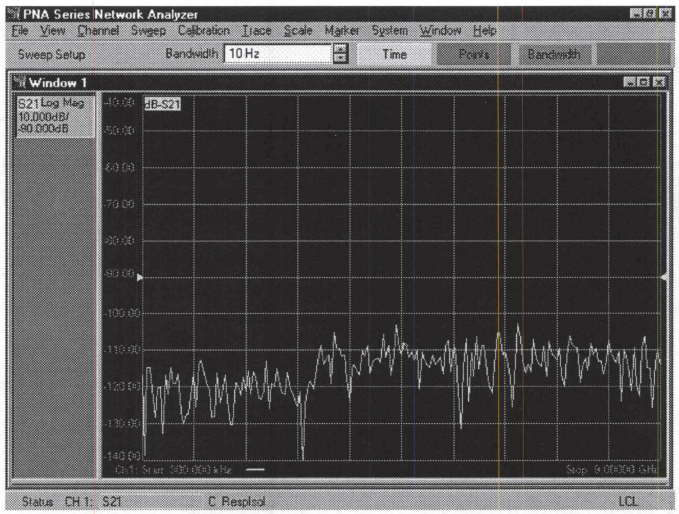
SLIDE 19

PNA measures –90dB in 3kHz IFBW; -115dB in 10Hz IFBW. **Change spec.'s shown here!**

N3383A 300kHz-9GHz PNA



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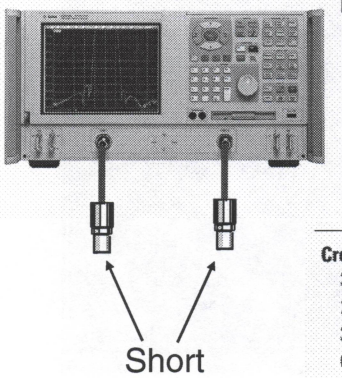
SLIDE 20

Lab Exercise : Crosstalk

Measure Cross Talk with Shorts on Test Ports
Compare to Specs



Measure S21
THRU Response Cal into Port 2 (+10 dBm)
Use 10 Hz IFBW
8 Averages

(Examine Alternate Mode)

Crosstalk	
300 kHz to 25 MHz	< –125 dBm
25 MHz to 3 GHz	< –128 dBm
3 GHz to 6 GHz	< –118 dBm
6 GHz to 9 GHz	< –113 dBm

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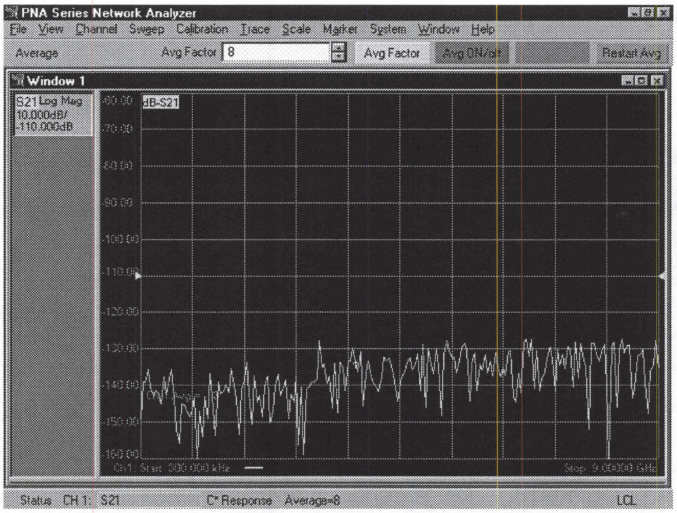
SLIDE 21

N3383A 300kHz-9GHz PNA Crosstalk



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SLIDE 22

Exercise
--Power Sweep

Let's Practice

1. **Preset the VNA**
2. **Set up Power Sweep from –20 dBm to –13 dBm**
3. **Set CW Frequency to 1 GHz**
4. **Measure S21 Gain through LAB amplifier (8447D)**
5. **Determine 1dB-Compression point**

Try viewing S21 Phase and determine AM-to-PM conversion.*

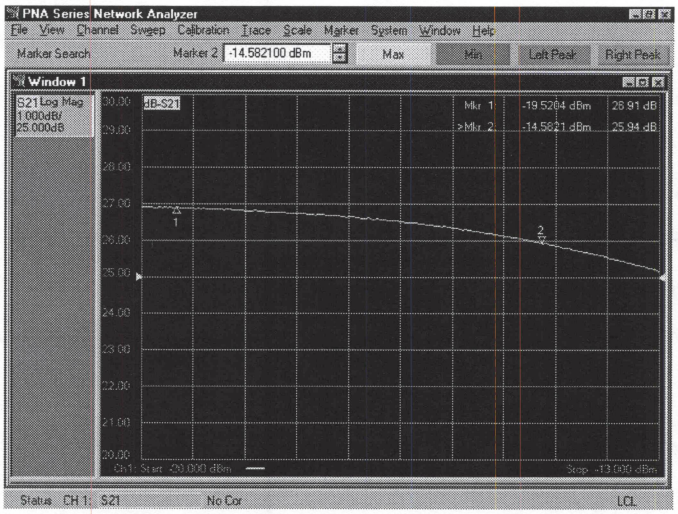
Agilent Technologies

SLIDE 23

Make sure the amplifier used does not output power exceeding +20dBm to either Port 1 or Port 2 of the Network Analyzer.

To set the attenuation in Power Sweep, click [Channel]—>Power after selecting Power Sweep.

8447D Amplifier



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SLIDE 24

Shown above is the resultant S21 power sweep of an Agilent 8447D amplifier with typical gain of 25dB. The amplifier is being measured at a center frequency of 1GHz. Marker 1 (small-signal) gain is 26.9 dB. Marker 2 shows the 1-dB compression point (25.9dB gain) at an input power of –14.6dBm. The 8447D Amplifier has a specified 1-dB compression of +7dBm (*output power*). Subtracting the specified 25dB of gain from the output compression level gives a specified *input power* 1-dB compression point of –18dBm. The amplifier exceeds this specification, and maintains linearity with slightly higher input power levels.

Exercise—Filter Tuning

- Set START/STOP frequencies and power for measurement of lab filter
- Perform a Full 2-Port calibration
- View 4-screen display
  - S11 LogMag
  - S11 Smith Chart
  - S21 Log Mag
  - S21 Phase
- Add a length of cable to filter input and view changes

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SLIDE 25

EXERCISE
Electrical Delay and Group Delay

1. **Perform Full 2-Port CAL at lab filter frequencies.**
2. **Set START/STOP frequencies to cover lab filter range.**
3. **Connect lab filter between Port 1 and Port 2.**
4. **Measure S21 PHASE.**
5. **Flatten phase response by dialing in <Electrical Delay>. (In the PNA, with the Marker centered on the phase trace, use [Marker Function] and >>Delay.)**
4. **View S21 in GROUP DELAY format.**

**** If possible, also display S21 LOG MAG. ****
**** What does Electrical Delay tell us? ****

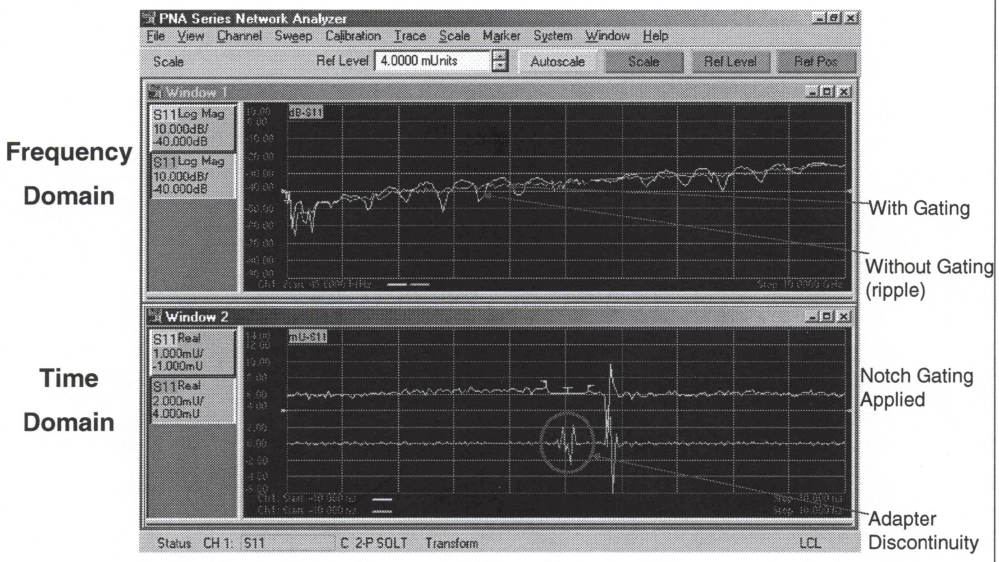
Agilent Technologies

SLIDE 26

When using a PNA, the required electrical delay needed to flatten a phase response can be obtained as follows:

Turn on Marker (should appear in center); then press [Marker Function] and >Delay. (7.546535nsec; 2.262394263 m on the 10.24GHz BPF. Group Delay = -800ps)

Exercise—Time Domain



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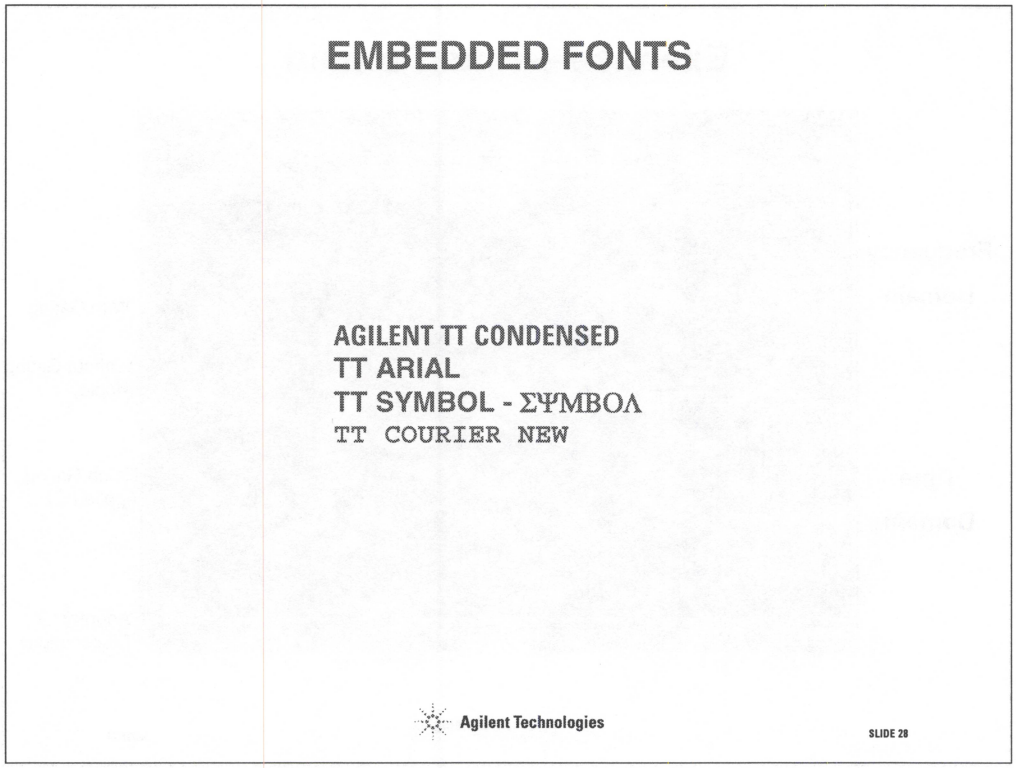
SLIDE 27

1. Connect 3.5mm (male-to-male) cables to PNA Ports 1 and 2.
2. Connect 3.5mm (female-to-female) adapter to the Port 2 cable.
3. Perform a Full 2-Port Calibration from 45MHz to 10GHz.
4. View S11 Log Mag. Notice the ripples in the trace caused by reflections from the adapter.
5. Select [Trace]→Transform→Low Pass Impulse and set [Format]→Real and AutoScale.
6. Select Real Format on the time domain S11 trace and AutoScale.
7. To gate out the response from the adapter, select [Trace]→Transform→Gating→Notch and center the gate around the adapter discontinuity (the first one).
8. Look back at the frequency domain by turning off [Transform] and view Log Mag of S11.
9. Turn gating ON and OFF to view the improvement from gating out the effects of the adapter.

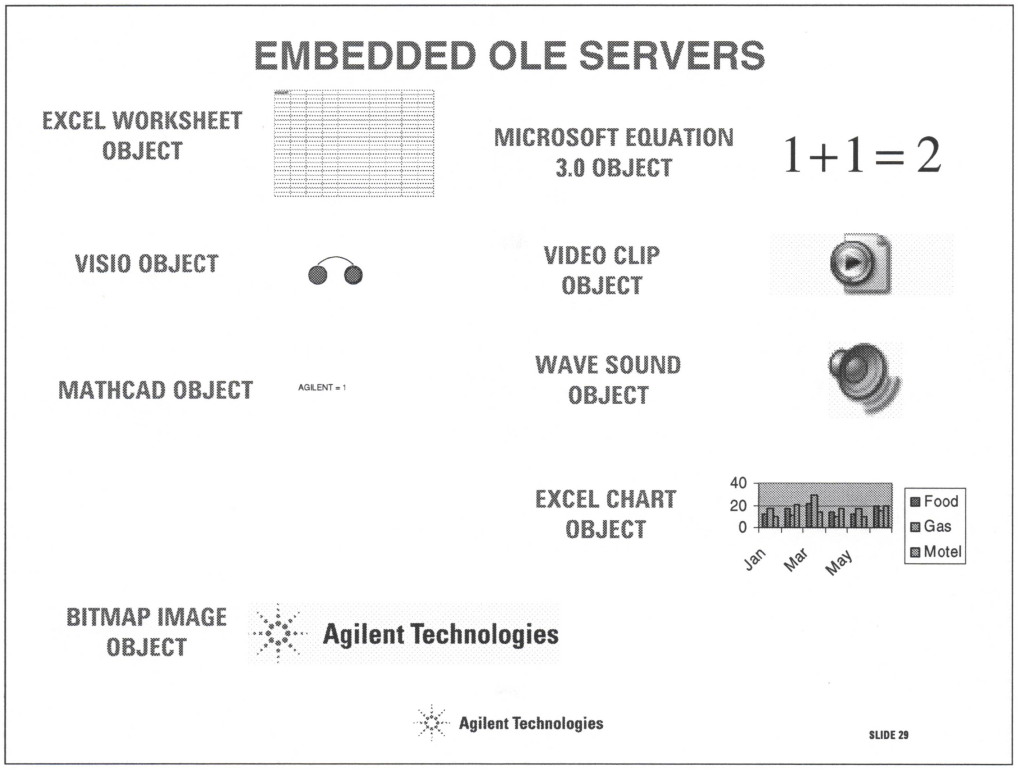


THIS SLIDE SHOWS THE EMBEDDED FONTS IN TEMPLATE.

TEMPLATE USERS ARE NOT ABSOLUTELY REQUIRED TO USE ONLY THE EMBEDDED FONTS, BUT IT IS RECOMMENDED.

IN PART, THE GENESIS OF THIS TEMPLATE, IS TO ELIMINATE THE FREQUENT PROBLEM OF SLIDES WITH FONTS THAT ARE NOT RESIDENT ON PC'S WITHIN THE USER COMMUNITY. BY LIMITING THE NUMBER OF FONTS AND EMBEDDING THEM INTO THE TEMPLATE, WE INTEND TO ELIMINATE THE PROBLEM OF SLIDE SETS THAT APPEAR CORRUPTED DUE TO LOCAL FONT SUBSTITUTION.

IF YOU REQUIRE AN ALTERNATIVE FONT FOR YOUR PRESENTATION, PLEASE EMBED THAT FONT IN YOUR PRESENTATION.



THIS SLIDE CONTAINS OLE OBJECTS AND CAUSES EMBEDDING OF THE RESPECTIVE OLE SERVERS IN THE TEMPLATE.

LEAVE THIS SLIDE AT THE VERY END OF THE PRESENTATION WHICH SHOULD FORCE THE OLE SERVERS TO REMAIN EMBEDDED IN YOUR PRESENTATION.

PLEASE EMBED ANY ADDITIONAL OLE SERVERS YOUR PRESENTATION MAY REQUIRE.

Network Analyzer Labs
8753ES / 8720ES
7/28/06

EXERCISE 1
Network Analyzer Set-up

1. **Preset the Analyzer (no DUT connected; no CAL)**

2. **Set the START and STOP frequencies from 30kHz – 3GHz**

3. **Set Port 1 POWER to –10dBm**
   (Menu->Power -> -10 "x1")

4. **Select measurement types S11 and S21**
   Ch1 -> Meas -> S11 Ch2 -> Meas -> S21

5. **Select units (LOG MAG) – Format –> Log Mag**

6. **Set up DISPLAY for split screen (S11 top, S21 bottom)**
   Display - > Dual/Setup -> Dual Chan ON

7. **Set up DISPLAY for overlay screen (S11 and S21 on same plot)**
   Display -> Dual -> Split Display -> 1x

EXERCISE 2 - Smith Chart

1. **Preset the Analyzer (no CAL)**

2. **Set the START and STOP frequencies from 30kHz – 3GHZ**

3. **Measure S11 of a type-N SHORT**

4. **View LOG MAG and Smith Chart**
   Format -> Log Mag **Format – Smith Chart**

5. **Repeat for type-N OPEN and type-N LOAD**

Where does the SHORT appear in the Smith Chart?
Where does the OPEN appear in the Smith Chart?
Where does the LOAD appear in the Smith Chart?

EXERCISE 3 - Coupler Directivity

1. **Preset the Analyzer (no CAL)**
2. **Meas -> S11**
3. **Connect Type-N Short standard to port 1 of Network Analyzer**
4. **Display -> "Data->Mem"**
5. **Display -> Data/Mem (Normalize trace to short response)**
6. **Connect 50 ohm load to port 1 of the network analyzer**
7. **Press Marker hardkey**
8. **Rotate knob to move marker across frequency range and check results against specifications of network analyzer. The specification will be listed as the uncorrected directivity in the network analyzer specifications.**

EXERCISE 4 -Directivity Error Effects

1. **Preset the Analyzer (no CAL)**

2. **Set the frequencies over entire range of the lab filter**
   Center Frequency = 200 MHz
   Span = 390 MHz

3. **Connect Port 1 to Filter INPUT**

4. **Measure S11**

5. **View LOG MAG**

Does the trace appear flat?*
What causes the non-flatness?*

EXERCISE 5 - SHORT Verification

1. **Preset the Analyzer (no CAL)**
2. **Set the START and STOP frequencies from 2GHz – 2.5GHZ**
3. **Connect type-N SHORT to Port 1**
4. **Measure S11**
5. **Press Marker Hardkey**
6. **LOG MAG** -.2 **dB @ 2.25 GHz**
7. **PHASE** 140.2 **degrees @ 2.25 GHz (Format -> Phase)**

What reflection do you expect to see?

EXERCISE 6 - THRU Verification

1. **Preset the Analyzer (no CAL)**
2. **Set the START and STOP frequencies from 30 kHz – 3 GHz**
3. **Connect a thru-cable between Port 1 and Port 2**
4. **Measure S21**
5. **Scale Ref -> Autoscale**
6. **Marker**
7. **LOG MAG** .8 **dB @ 3 GHz**
8. **PHASE** 24.4 **degrees @ 3 GHz (Format -> Phase)**

What transmission characteristics do you expect to see?

EXERCISE 7 - Display Set-ups

Connect lab filter between Port 1 and Port 2

- **Set up frequencies to match lab filter range**
  CF = 200 MHz, Span = 150 MHz

- **Display -> Dual/Quad Setup -> 4-parameter displays -> Setup A**

- **Ch1 -> S11 Format -> LogMag**
  Ch2 -> S21 Format -> LogMag
  Ch3 -> S21 Format -> Phase
  Ch4 -> S22 Format -> LogMag

- **Scale Ref -> Autoscale (for all channels)**

EXERCISE 8
Electrical Delay and Group Delay

1. **Preset the Analyzer (no CAL)**

2. **Set frequencies to cover lab filter range CF = 200 MHz, Span = 150 MHz**

3. **Connect lab filter between Port 1 and Port 2**

4. **Measure S21 PHASE**

5. **Flatten phase response by dialing in <Electrical Delay>**
   Cal -> More -> Port Extensions -> Extensions ON
   Extensions Port 1 -> Turn Knob CW until trace flattens out

6. **Turn off Port Extensions**

7. **Measure S21, Format -> GROUP DELAY**

If possible, also display S21 LOG MAG.
What does Electrical Delay tell us?

EXERCISE 9 - Markers

1. View S21 LogMag of the lab filter (CF=200 MHz, Span = 150 MHz)

2. Place a marker on the filter center frequency (Marker -> 200 MHz)

3. Measure out-of-band rejection
   Mkr -> Mkr Zero -> Turn knob CW to reach noise floor – Read value 75MHz

4. Marker Off

5. Add S11 of lab filter to Network Analyzer and view LogMag

6. Place a marker at the filter center frequency and measure Return Loss -21dB

7. Set up 4-Screen DISPLAY showing
   Ch1 -> S11 Format -> Log Mag
   Ch2 -> S21 Format -> Log Mag
   Ch3 -> S21/2 Format -> Phase
   Ch4 -> S11 Format -> Smith Chart

7. Press MKR and note how markers are coupled together

Exercise 10 - Port Extension

Set up S21 LogMag and Phase of cable or filter

Cal -> More -> Port Extensions -> Ext ON –> Ext Port 1

Rotate knob to add positive port extension.

*****What changes?*****

Exercise 11: Full 2-port Calibration(1/4)

Set-up the VNA for a 2-port measurement of lab filter
    CF=200 MHz, Span = 150 MHz, S21 LogMag

Perform a full 2-port calibration
Cal –> Cal Kit -> Select Cal Kit -> 85032B/E ->Return -> Return
Calibrate Menu -> Full 2-port -> Reflection

Connect Open to Port 1 Cable:
    Forward Opens: -> Open(F) -> Done: opens
    (Note that sex refers to VNA port – not device under test)
Connect Short to Port 1 Cable:
    Forward Shorts: -> Short(F) -> Done: shorts
Connect Load to Port 1 Cable: Forward Load:
Connect Open to Port 2:
    Reverse Opens: -> Open(M) -> Done: opens
Connect Short to Port 2:
    Reverse Shorts: -> Short(M) -> Done: shorts
Connect Load to Port 2:
    Reverse Load: -> Load

Continued on next slide

Exercise: Full 2-port Calibration (2/4)

Standards Done
- Connect Port 1 cable to Port 2 of VNA:
  - Transmission -> Do both Fwd & Rev
- Isolation -> Omit Isolation
- Done 2-port Cal
- Save -> Save State REG5

Verify the Calibration:

Measure S11, Format -> Smith Chart
- Connect Open, Short, and Load standards – Repeat for S22
- Connect Thru Standard – Measure S21, Format -> Log Mag

Are the opens and shorts in the expected locations on the Smith Chart?

Exercise: Full 2-port Calibration (3/4)

Note: Most calibration standards consist of an offset open or short.

These offsets are a transmission line between the calibration plane and the actual open or short.

These offsets will cause the Smith Chart trace to wrap around the chart when re-measuring the standard.

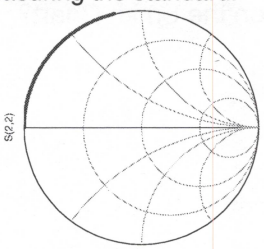


Table A-3 Standard Definitions

System Z_0[a] = 50 Ω Calibration Kit Label: N 50Ω

Standard[b]							Offset			Freq (GHz)			
Number	Type	C0 ×10^{-15} F	C1 ×10^{-27} F/Hz	C2 ×10^{-36} F/Hz^2	C3 ×10^{-45} F/Hz^3	Fixed or Sliding[c]	Delay (ps)	Z_0 Ω	Loss (Ω/s)	Min	Max	Coax or Waveguide	Standard Label[d]
1	Short						0.002	49.992	700M	0	999	Coax	Short (m)
2	Open	119.09	−36.955	26.258	5.5136		0	50	700M	0	999	Coax	Open (m)
3	Load					Fixed	0	50	700M	0	999	Coax	Broad-band
4	Delay/ Thru						0	50	700M	0	999	Coax	Thru
5													
6													
7	Short						17.817	50.209	2.1002G	0	999	Coax	Short (f)
8	Open	62.140	−143.07	82.920	0.7600		17.411	50	700M	0	999	Coax	Open (f)

a. Ensure system impedance (Z_0) of network analyzer is set to this value.
b. Open, short, load, delay/thru, or arbitrary impedance.
c. Load or arbitrary impedance only.
d. Standard labels that specify sex, (m) or (f), refer to the sex of the analyzer's test port connector.

Exercise: Full 2-port Calibration (4/4)

Measure the Filter:

Measure the insertion loss (S21) and return loss (S11) of the filter. Display both traces on at the same time and place markers on both traces.

Compare Corrected and Uncorrected Results:

Cal -> Correction On/Off (Toggle On/Off)

Make sure state was saved previously in slide 1/4

Change power level, IF BW, frequency range, etc.

What affect does changing these settings have on the calibration?

Exercise 12 - Changing IF Bandwidth Noise Floor

- Preset the VNA
- Meas -> S21
- Scale Ref -> Ref Value = -100 -> x1
- Display -> Data -> Mem
- Display -> Data and Mem
- Avg -> IFBW
- Press down arrow key and change IFBW until IFBW = 10 Hz

- How much did the noise floor drop with the change in IFBW from 3700 Hz to 10 Hz? What is the tradeoff?

Answer: 10 log(3700/10) = 25.7 dB

Exercise 13-Changing IFBW-Trace Noise

- Preset the VNA
- Set up for S21 with IFBW = 10Hz (slow sweep time)
  Meas -> S21, Avg -> IFBW -> 10 -> x1
- Connect DUT– long cable or filter—between Port1 and Port2
- Perform a THRU Response CAL
  Cal -> Calibrate Menu ->Response -> Thru (wait for sweep)
- Set SCALE to 1dB/div and save trace to memory
  Scale Ref -> Scale/Div -> 1 -> x1
  Display -> "Data -> Memory"
- Display both memory and measurement on one screen
  Display -> Data and Memory
- Increasing IFBW with up arrow key to 6000 Hz to decrease sweep time.
- View the response. Has it changed?
- What are the sweep times for each trace?

IF	Sweep
6000 Hz	87.5 ms
10 Hz	20.8265

Exercise 14 – Segmented Sweep

- Preset
- Meas -> S21
- Menu -> Sweep Type Menu

- Edit List -> Add -> Start -> 100 MHz, Stop -> 150 MHz, Num Pts = 51
  More -> List IFBW ON -> Segment IFBW -> 10 -> x1 -> Return -> Done

- Add -> Start -> 150 MHz, Stop -> 250 MHz, Num Pts = 101
  More -> Segment IFBW -> 3 kHz -> Return -> Done

- Add -> Start -> 250 MHz, Stop -> 300 MHz, Num Pts = 51
  More -> Segment IFBW -> 10 -> x1 -> Return -> Done -> Done

- List Frequency (Swept)
- ScaleRef -> AutoScale

- What would sweep time be if you used a 10 Hz IFBW from 100MHz to 300 MHz instead of the segmented sweep?

Exercise 15 - Power Sweep

IMPORTANT:

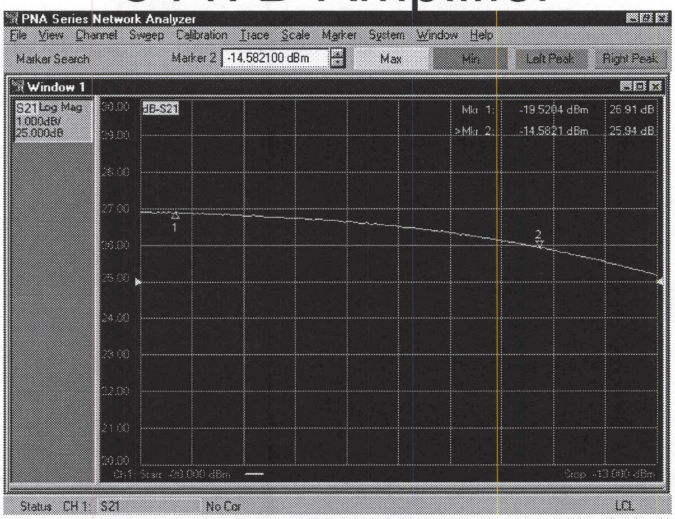
Attach a 20 dB attenuator to the output port of the 8447D amplifier before proceeding. This will protect the VNA from damage. Turn 8447D amplifier off.

- Preset the VNA
- Set up Power Sweep from –20 dBm to –13 dBm
  Menu -> Sweep Type Menu -> Power Sweep
  Start -> -20 -> x1 (-20 dBm)
  Stop -> -13 -> x1 (-13 dBm)
- Set CW Frequency to 1 GHz
  Menu -> CW Freq -> 1 GHz
- Power 8447D on and measure S21 Gain through LAB amplifier (8447D)
- Determine 1dB-Compression point
  Scale Ref -> Autoscale
  Marker -> -20 -> x1 -> Mkr Zero -> Rotate knob CW to find 1 dB point

Try viewing S21 Phase and determine AM-to-PM conversion.

Display -> Dual | Quad Setup -> Dual Display ON
CH2 -> Format -> Phase -> Scale Ref -> Autoscale

8447D Amplifier



Shown above is the resultant S21 power sweep of an Agilent 8447D amplifier with typical gain of 25dB. The amplifier is being measured at a center frequency of 1GHz. Marker 1 (small-signal) gain is 26.9 dB. Marker 2 shows the 1-dB compression point (25.9dB gain) at an input power of –14.6dBm. The 8447D Amplifier has a specified 1-dB compression of +7dBm (*output power*). Subtracting the specified 25dB of gain from the output compression level gives a specified *input power* 1-dB compression point of –18dBm. The amplifier exceeds this specification, and maintains linearity with slightly higher input power levels.

Exercise 16 -Time Domain (1/2)

Connect Type-N (f) to 7mm adapters to both ports of 8753ES

Perform a 1 port Calibration on Port 1 of the VNA
Preset -> Cal -> Cal Kit -> Select Cal Kit -> 85032B/E -> Return -> Return
Calibrate Menu -> S11 1-port
Forward: Opens -> Open(F) -> Done: Opens
Forward: Shorts -> Short(F) -> Done: Shorts
Forward: Load -> Done 1-port Cal
Save/Recall -> Save State

Connect Type-N to BNC(f) adapters to both ports

Connect BNC (m-m) cable between ports 1 & 2 of 8753

System -> Transform Menu -> Low Pass Impulse – Transform ON
Format -> More -> Real
ScaleRef -> Autoscale

Disconnect BNC cable at one end and view time domain response –
Reconnect cable after experimenting

Exercise 16—Time Domain Gating (2/2)

System -> Transform Menu -> Specify Gate -> Center

Turn knob so gate center (T) is at leftmost discontinuity

Span (softkey not hardkey)

Turn knob so gate edges just surround first connector discontinuity

By default when gating is activated, the VNA gates out all values outside of gate. To ignore values within the gate enter a negative gate span

E.g. if the width of the gate is 1.511 ns, then enter -1.511 ns

Gate ON (zero out connector discontinuity) -> Return

The gate is now applied. To view the frequency response of the cable with the interface gated out:

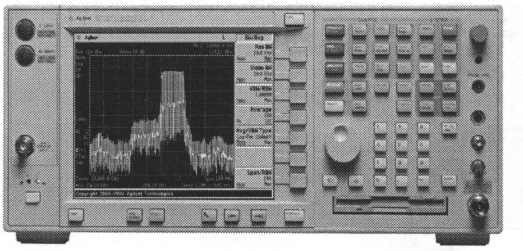
Transform OFF

Format -> Log Mag

System -> Transform Menu -> Specify Gate

Toggle Gate on and off to see results with and without gating

Spectrum Analysis Lab



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Demo 1 – Slide 39

Preset ESG, ESA, and PSA.

Set ESG frequency to 200 MHz.

Set ESG power to –10 dBm.

Turn ESG RF On.

Set centre frequency of ESA and PSA to 200 MHz.

Set span of SA's to 2 MHz.

Turn on Averaging. Set Average number to 10.

Set the RBW of the SA's to 300 kHz. Notice how the spectrum analyzer's trace out the shape of the filters.

Reduce the RBW of the SA's to 30 kHz using the arrow keys and pausing at 100 kHz to show the change as you reduce the RBW.

ESG

Mode->More(1 of 3)->Multitone

Initialize Table-> Select 2 tones with 10kHz spacing and random phase and seed

Multitone On

PSA and ESA

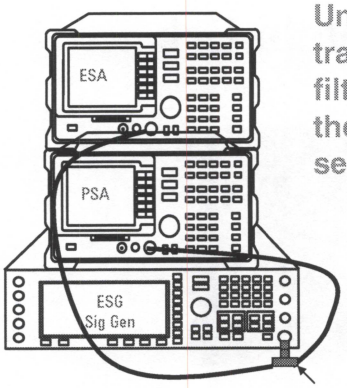
Set span to 200 kHz.

Set RBW to 3 kHz. Notice the difference between the Digital and Analog RBW filters The ESA shows the 2 tones but no distortion. The PSA shows the beginning of the IMD products.

Reduce RBW to 1 kHz. The PSA now clearly sees the IMD products and the ESA begins to see them.

Demo

RBW Filter, Filter Type, Filter Selectivity



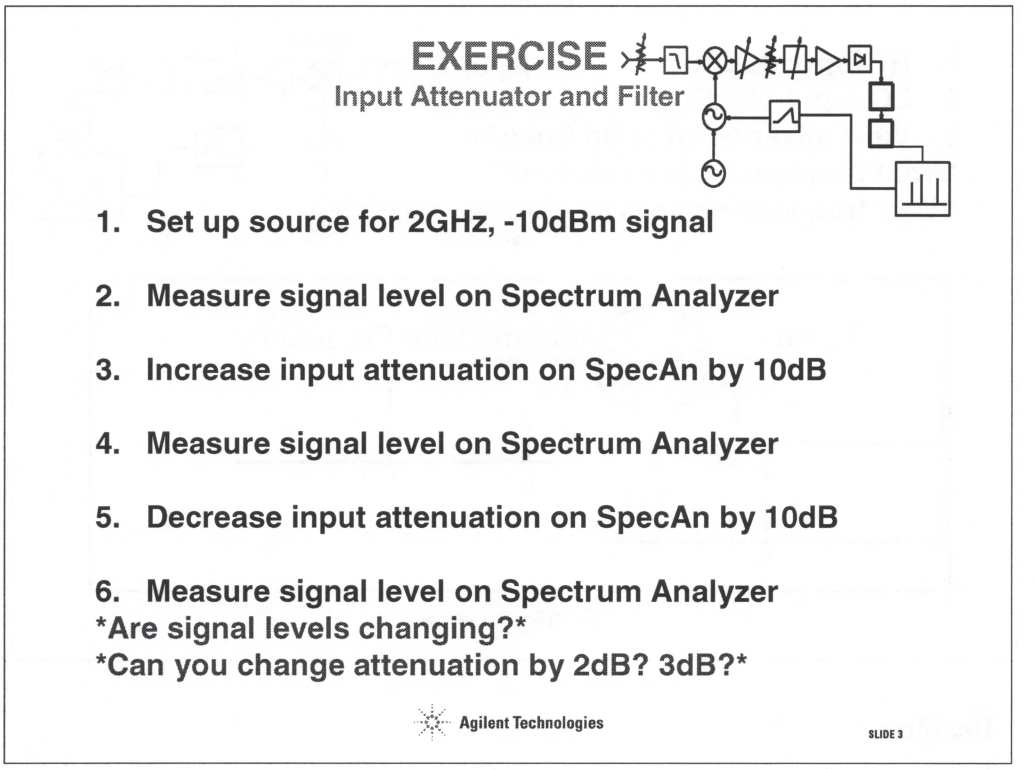
Unknown signal – Show the signal tracing out the shape of the RBW filter. Reduce the filter BW to show the effects of filter type and filter selectivity.

BNC Tee

Agilent Technologies

SLIDE 2

Slide 39

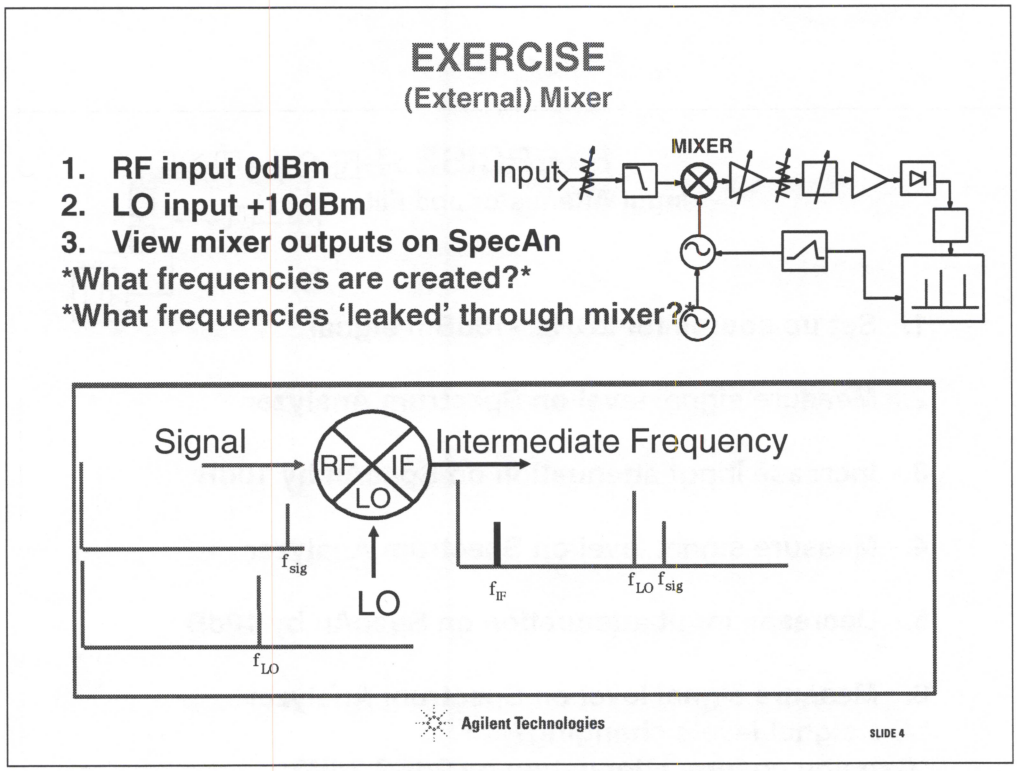


Input Attenuator:

The RF input attenuator is used to adjust the level of the RF signal into the mixer. It is important to be able to do this in order to protect the mixer from large signals and to control the spurious free dynamic range of the spectrum analyzer. The RF attenuator may be set to zero dB, however this condition must be used with care, analyzer designers have used mechanical interlocks or special button sequences to avoid an operator accidentally selecting 0dB attenuation. Most analyzers have attenuators with the range 0dB to 70dB with ten or five dB step selection.

Input Filter:

This limits the amount of RF energy to the band of the analyzer. In an RF analyzer this band is the whole RF bandwidth of the instrument. In a microwave spectrum analyzer (for example > 3GHz) this filter is a tunable bandpass filter which tunes with the sweep, called a *microwave preselector*.



The Mixer:

There are many mixing stages in a spectrum analyzer, we can explain the function of the analyzer by treating it as a simple one stage receiver.

Mixers are three-port devices that convert a signal from one frequency to another, the mixer may be called, a frequency translation device.

The RF input signal is applied to the input port, and the Local Oscillator signal to the L port. The LO is a high level signal (> +10dBm) compared to the RF (< –10dBm).

A mixer is a non-linear device, this means that besides the wanted frequency translated signal, there are a number (theoretically an infinite number) of signals we don't want.

The wanted signals from the mixer are ($f_R - f_L$) or ($f_L - f_R$), positive quantities.

It is this difference frequency that is of interest in the spectrum analyzer, We call this signal the IF signal, or Intermediate Frequency signal.

Microwave Spectrum Analyzers.

The IF is a relatively low frequency, so the LO must generate frequencies over the same nominal frequency range as the analyzer's input frequency range. In microwave spectrum analyzers, therefore, to avoid the expense of providing a fundamental LO which would be a wide range microwave LO, multipliers may be used or more usually harmonic relationships at the mixer output are used.

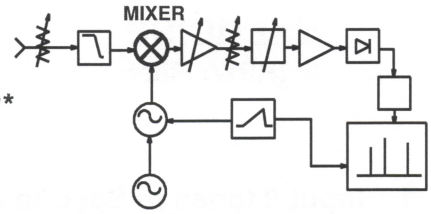
$$(f_R - n.f_L) \text{ or } (n.f_L - f_R)$$

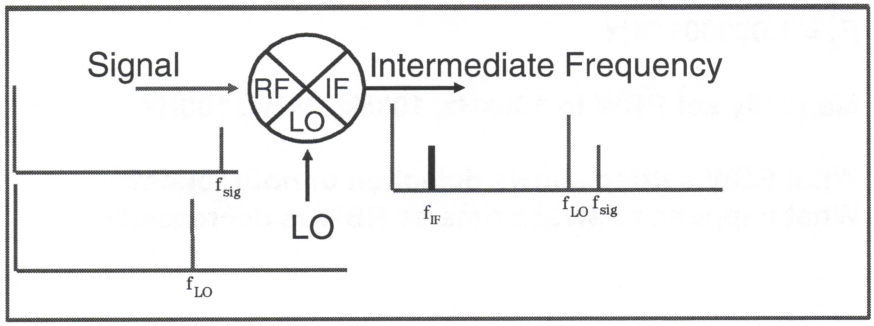
EXERCISE (Cont.'d)

(External) Mixer

1. **Increase RF power to +10dBm**
2. **View mixer output**

Are more frequencies generated?
What is the cause of this?



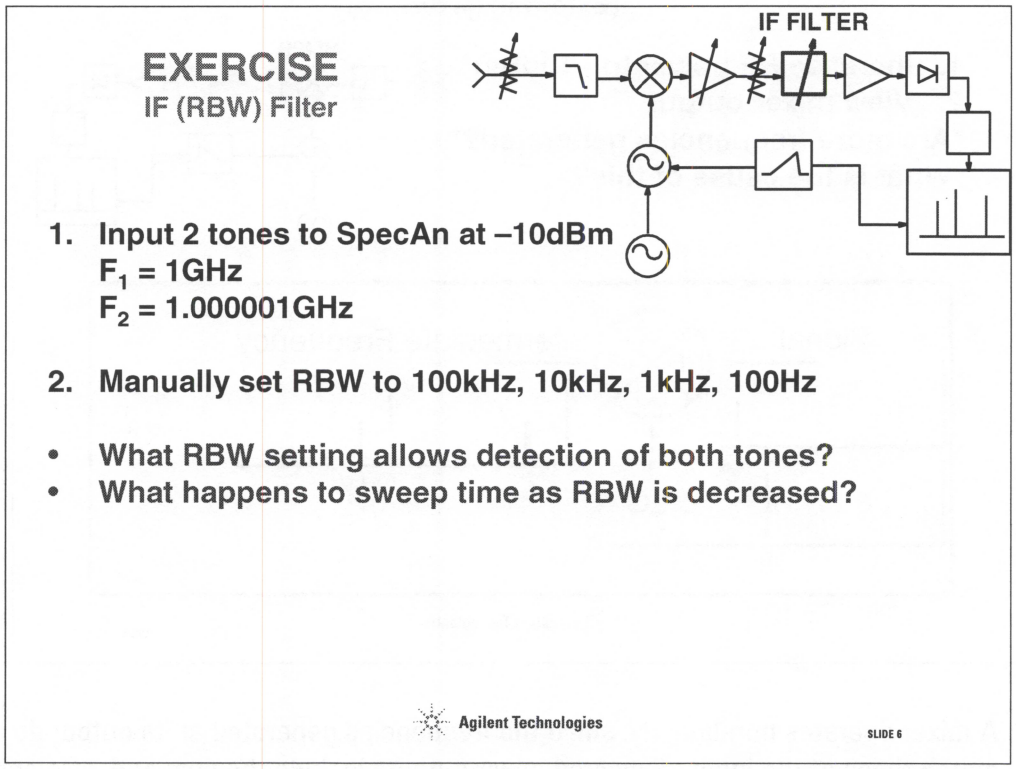


Agilent Technologies

SLIDE 5

A mixer operates non-linearly, since the frequencies generated at its output do not match those at the input. Expected mixer outputs include the sum and difference frequencies ($f_{LO} \pm f_{SIGNAL}$) and some LO-to-IF leakage. A mixer's isolation determines the amount of leakage between the LO and IF ports

Typical mixer LO port drive levels are between +7 and +10dBm, with SIGNAL levels at or below 0dBm. When a mixer is overdriven, or too much power is applied to its SIGNAL input port, the mixer diodes create additional frequencies at the mixer output. These frequencies are distortion products of the mixer. Therefore, if the input power to a spectrum analyzer overdrives the first stage mixer (downconverter), the spectrum analyzer will generate internal distortion products. The input attenuator is used to set spectrum analyzer input levels for minimum distortion.



The Intermediate Frequency (IF) or Resolution Bandwidth (RBW) Filter:

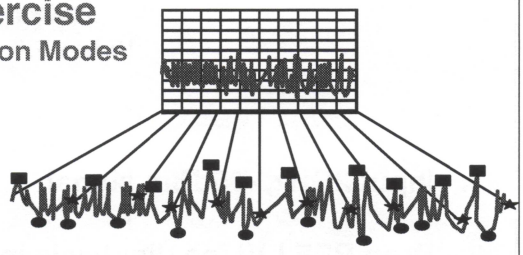
The IF filter is also known as the Resolution bandwidth filter. When you change the RBW on the analyzer, you change the bandpass width of this filter.

The IF filter is a bandpass filter that is used as the "window" for detecting signals. Spectrum analyzers typically give several choices of RBW settings. By having a broad range of variable RBW settings, the analyzer can be optimized for a given measurement condition.

The example in this illustration shows that as the filter is narrowed, selectivity is improved and two closely spaced input signals may be resolved. This will, however, slow down the sweep speed.

The resolution bandwidth filter will be discussed in other parts of this class.

Exercise
Detection Modes



1. No input to SpecAn
2. Drop REF LVL to display noise in center of screen
3. Select SAMPLE, POSITIVE PEAK, and NEGATIVE PEAK detector modes

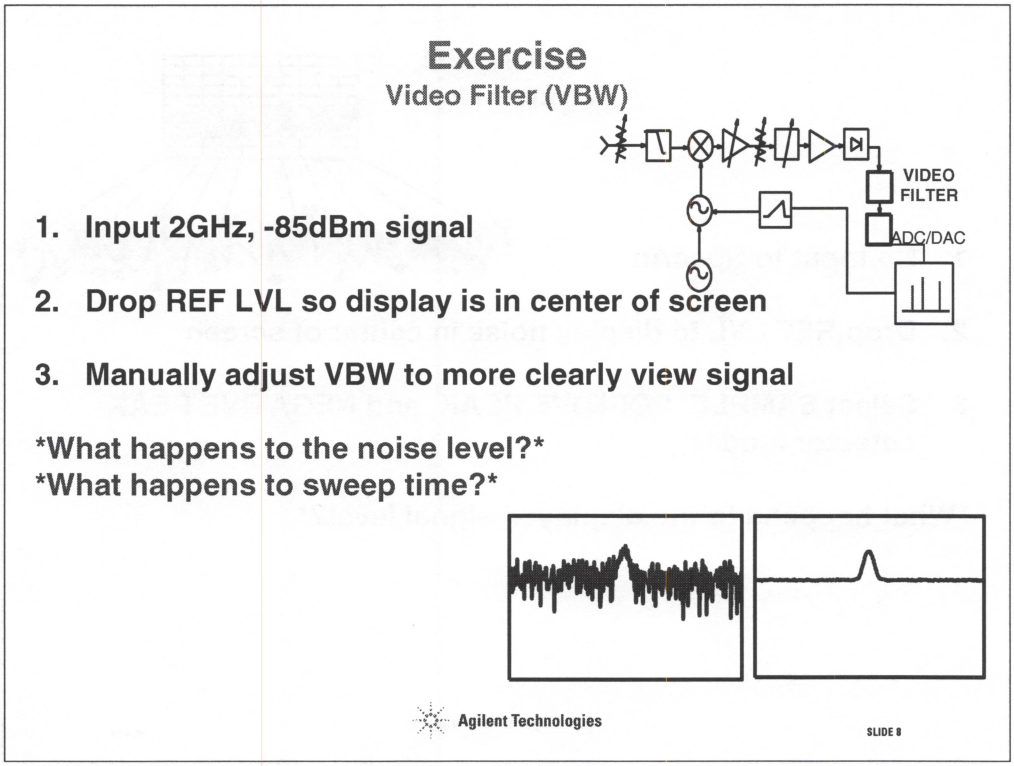
What happens to the displayed signal level?

Agilent Technologies

SLIDE 7

In some Agilent spectrum analyzers the default mode uses a special algorithm which has been given the name "rosenfell"* mode. This mode is designed to display noise without bias and CW signals properly. For example, if the signal both rose and fell within a sampling bin, it assumes it is noise and will use the positive & negative detector alternately. If it continues to rise, it assumes a CW signal and uses positive peak detector.

* The name is derived from " if the data rose and fell, then. . ."

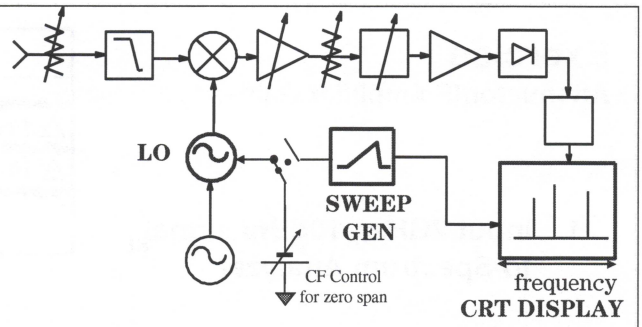


The video filter is a low-pass filter that is located after the detector and before the ADC.

It is used to average or smooth the trace that is seen on the display, as shown on the slide. As the video filter BW is decreased the trace will become smoother . **A change in video BW does not change the mean noise level**. The small decrease in displayed noise level observed, when the VBW filter is reduced and the positive peak detector is in effect, is because the displayed noise is biased above the mean by the +ve peak detection process.

The smoothing of the displayed noise allows signals close to the noise level to be observed. Remember that the displayed trace represents signal + noise, *even when the noise is smoothed.*

Exercise
Local Oscillator



1. **Set SpecAn to 1GHz CTR freq.**
2. **Set SPAN to (Zero SPAN)**

What happens to the x-axis display?

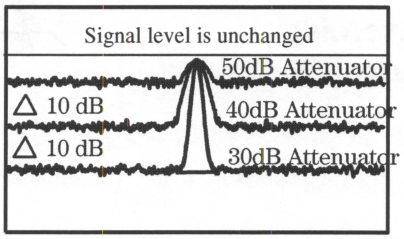
Agilent Technologies

SLIDE 9

The LO is a voltage controlled oscillator (VCO) which provides the LO signal for to the mixer. A sweep generator provides the ramp voltage to tune the LO in proportion to the ramp voltage. It also controls the horizontal position of the trace displayed on the spectrum analyzer display. This makes the display X axis the frequency axis. The ramp voltage may be switched from the LO while still sweeping the display, in this mode the analyzer behaves like a fixed tuned receiver. This is called *zero span* or *zero scan*, the tuned frequency may be changed like changing stations on an AM radio.

Exercise

Attenuator/IF Amplifier Gain



1. **Input 2GHz, -10dBm signal to Spectrum Analyzer**
2. **Increase input ATTEN to 30db, 40dB, 50dB**
3. **View changes in noise level; signal level remains same**

Increased Attenuation = Decreased Signal/Noise ratio.

4. **Set ATTEN to <Auto> and vary RBW**
5. **View changes in noise level; signal level remains same**

Agilent Technologies

SLIDE 10

The Displayed Average Noise Level, DANL, is also a function of RBW:

The internally generated noise in a spectrum analyzer is random and has no discrete spectral components. Also, its level is flat over a frequency range that is wide compared to the RBW ranges.

This means that the total noise reaching the detector (and displayed) is related to the RBW selected.

Since the noise is random, it is added on a power basis, so the relationship between displayed noise level and RBW is a ten log basis.

In other words, if the RBW is increased (or decreased) by a factor of ten, ten times more (or less) noise energy hits the detector and the displayed average noise level (DANL) increases (or decreases) by 10 dB.

EXERCISE
How it all works together

1. **Input a 1.5GHz, -10dBm signal to Spectrum Analyzer**
2. **Set CTR Freq. to 1.5GHz, SPAN to 4GHz**
3. **View spectral display components at 0Hz and 1.5GHz**

Is the 0Hz signal real?

Agilent Technologies

SLIDE 11

When the Spectrum Analyzer's LO sweeps to a frequency that matches the center of the IF (RBW) filter, leakage of that LO signal through the mixer will result in a 0 Hz defelection on the Spectrum Analyzer display.

EXERCISE
Front Panel Operation

1. Locate Frequency, Span, and Amplitude [Hardkeys]
2. Locate (Softkeys) on right side of screen
3. Notice how (Softkey) menu changes when different [Hardkeys] are pressed
4. Input a 2.5 GHz, -10dBm signal and locate it using the Frequency, Span and Amplitude [Hardkeys]
5. Optimize REF Level, Span, RBW and VBW

Agilent Technologies

SLIDE 12

Each Spectrum Analyzer [Hardkey] is a physical button on the front panel of the instrument. (Softkey) menus appear vertically along the right side of the display panel and change with each [Hardkey] that is pressed. When more (Softkeys) than can fit on one screen are available, pressing "more" or "2 of 3" will advance to the next screen of (Softkeys). "Return" will set the (Softkey) menu back to its previous state.

EXERCISE (if option is available)
Frequency Readout Accuracy

1. Input a 4 GHz, -10dBM signal to SpecAn
2. Set SpecAn to:

   4 GHz Center Frequency
   400 kHz Span
   3 kHz RBW

3. Use [Marker] function to perform a frequency count

4. Measure the readout accuracy

Agilent Technologies

SLIDE 13

EXERCISE
Technique for Best Accuracy

1. **Set SpecAn center frequency to 2 GHz.**
2. **Place the first signal (2 GHz, -10dBm) at the reference amplitude using the REF LVL control.**
3. **Measure 2 GHz power level.**
4. **Re-center the SpecAn to 2.007 GHz.**
5. **Move the second signal (2.007 GHz, -23dBm) to the same reference, measure power, and calculate the difference from the 2 GHz signal.**

Relative Amplitude in dB

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SLIDE 14

A technique for improving amplitude accuracy is to place the first signal at a reference amplitude using the reference level control, and use the marker to read amplitude value. Then move the second signal to the same reference and calculate the difference.

This assumes that the Reference Level Uncertainty (changing the reference level) is less than the Display Fidelity Uncertainty.

EXERCISE
RBW and Measurement Time

1. Input a 2GHz, -10dBm signal to SpecAn
2. Set RBW to <Auto> and view Sweep Time
3. Decrease RBW manually to 100Hz (sweep time=?)
4. Decrease Sweep Time and view UNCAL indicator and measurement errors

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SLIDE 15

Sweeptime:

When the resolution bandwidth is decreased, the selected filter time constant increases and so it needs more time to fully respond.

As sweeptime is decreased, for a given RBW filter, the displayed response will become progressively distorted both in amplitude and frequency. The displayed amplitude becomes lower as the filter does not fully charge, and the frequency shifts higher due to delay through the filter.

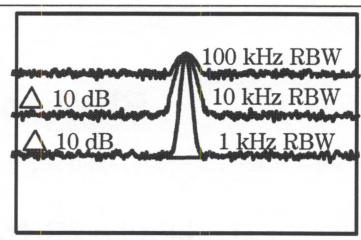
When selecting the RBW, there is usually a 1-10 or a 1-3-10 sequence of RBWs available (some spectrum analyzers even have 10% steps).

More RBWs are better because this allows choosing just enough resolution to make the measurement at the fastest possible sweeptime.

The spectrum analyzer firmware is programmed to adjust the sweeptime appropriately for the RBW, VBW and SPAN selected, this happens automatically when the instrument is in its default (preset) mode. This is called the *auto_coupled* state.

$$\text{sweeptime is a function of } \left(\frac{Span}{RBW^2}\right) \text{ and } \frac{1}{VBW}$$

EXERCISE
Sensitivity/DANL: IF Filter (RBW)



1. **Input a 2GHz, -80dBm signal to Spectrum Analyzer**
2. **Decrease REF LVL to view in center of screen**
3. **Change RBW to 100kHz, 10kHz, 1kHz and watch noise drop**

Decreased RBW = Decreased Noise

Agilent Technologies

SLIDE 16

The DANL is also a function of RBW:

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This means that the total noise reaching the detector (and displayed) is related to the RBW selected.

Since the noise is random, it is added on a power basis, so the relationship between displayed noise level and RBW is a ten log basis.

In other words, if the RBW is increased (or decreased) by a factor of ten, ten times more (or less) noise energy hits the detector and the displayed average noise level (DANL) increases (or decreases) by 10 dB.

EXERCISE
Distortion

1. **Input a 2GHz, +10dBm signal to Spectrum Analyzer**
2. **Measure distortion levels (any non-2GHz signals)**
3. **Increase signal power to +20dBm**
   make sure Spectrum Analyzer can handle this!!!
4. **Measure distortion levels**
5. **Change input ATTEN by 10dB to see if distortion products drop.**

****Is this distortion internally or externally generated?****

Agilent Technologies

SLIDE 17

Before leaving this section on distortion, there is a test that should be done for all distortion measurements which will tell us whether or not what we are seeing on the screen is internally generated distortion, or distortion caused by the DUT.

Remember that the RF input attenuator and the IF gain are tied together such that input signals will remain stationary on the screen when we adjust the RF input attenuation. So let's change the RF input attenuation and see what happens.

If the distortion product on the screen does not change, we can be sure it is distortion from the DUT (i.e. part of the input signal). The 10 dB attenuation applied to the signal is also experiencing the 10 dB gain from the IF gain and therefore, there is no change.

If however, the signal on the screen does change, then we know it must be being generated, at least in part, somewhere after the input attenuator, and not totally from the DUT. The 10 dB attenuation is not applied to this internal signal (since it is actually generated after the attenuator), yet the 10 dB gain is applied to it, therefore increasing its level by as much as 10 dB.

EXERCISE
Phase-Noise Measurement

1. **Input 2GHz, -10dBm signal to Spectrum Analyzer**

2. **Use [Phase Noise] button to make a SSB Phase-Noise plot**

3. **Measure Phase-Noise at the following offsets from the carrier**
   100Hz_____dBc/Hz
   1kHz_____dBc/Hz
   10kHz_____dBc/Hz
   1MHz_____dBc/Hz

4. **If possible, measure the DANL of the SpecAn and subtract this from the phase-noise measurement**

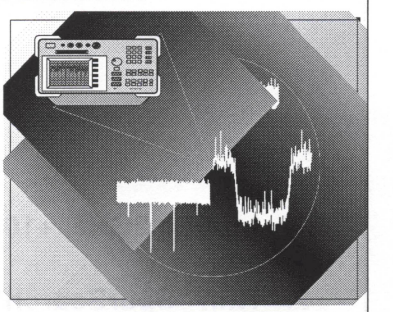
Agilent Technologies

SLIDE 18

The Phase-Noise measurement in a Spectrum Analyzer allows single-sideband (SSB) display of the input signal noise. Since the carrier is no longer present, lower sideband level detection than is available in the spectral view is possible.

If the Spectrum Analyzer has a "DANL" (displayed average noise level) measurement, this level can be measured, stored, and then subtracted from the phase-noise measurement of an input signal. This allows correction for the effects of DANL on phase-noise levels that are close to the Spectrum Analyzer's noise floor (DANL).

EXERCISE
Channel Power Measurements



1. Input a 2GHz, -10dBm signal
   QPSK modulation
   24.3kHz symbol rate
   .35 filter alpha

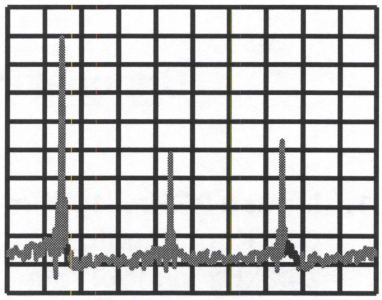
2. Measure [Channel Pwr] in a 50kHz bandwidth, centered at 2 GHz

3. View the in-channel and next adjacent channel power levels

Agilent Technologies

SLIDE 19

EXERCISE
Spurious Measurements

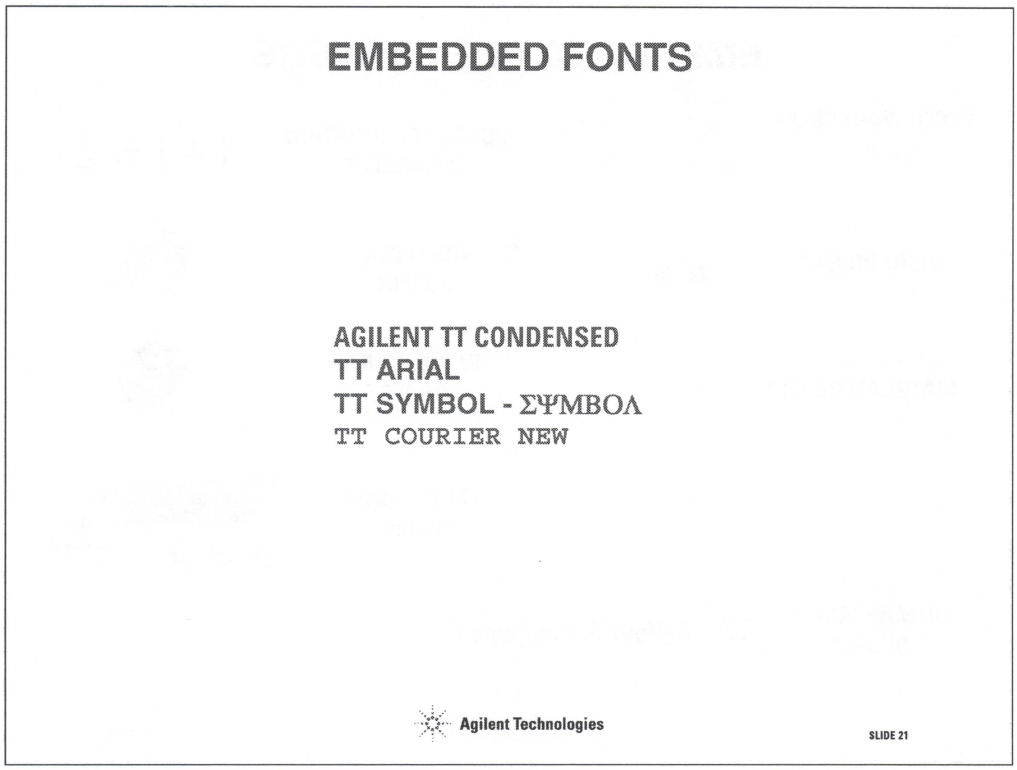


1. Input a 2GHz, +10dBm signal
2. Run "SpurSearch" measurement (if available)
3. View results screen
4. Vary the threshold for spur identification and run "SpurSearch" measurement again

Agilent Technologies

SLIDE 20

The newer Agilent Spectrum Analyzers, such as the E4440B, include a [Hardkey] function for spur searching. Pressing the [Spur Search] button begins and automatic search for any signals appearing other than the carrier. A list of spurs found is then displayed with frequencies and power levels. Changing the threshold for spurious allows users to select which spur levels will be listed.

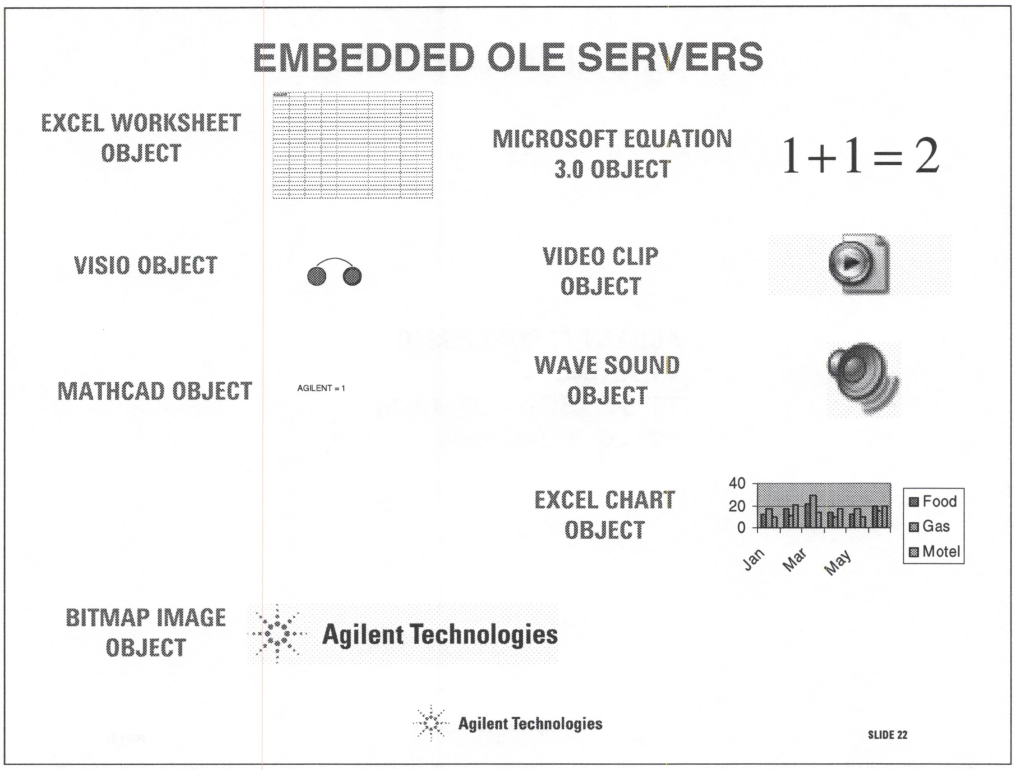


THIS SLIDE SHOWS THE EMBEDDED FONTS IN TEMPLATE.

TEMPLATE USERS ARE NOT ABSOLUTELY REQUIRED TO USE ONLY THE EMBEDDED FONTS, BUT IT IS RECOMMENDED.

IN PART, THE GENESIS OF THIS TEMPLATE, IS TO ELIMINATE THE FREQUENT PROBLEM OF SLIDES WITH FONTS THAT ARE NOT RESIDENT ON PC'S WITHIN THE USER COMMUNITY. BY LIMITING THE NUMBER OF FONTS AND EMBEDDING THEM INTO THE TEMPLATE, WE INTEND TO ELIMINATE THE PROBLEM OF SLIDE SETS THAT APPEAR CORRUPTED DUE TO LOCAL FONT SUBSTITUTION.

IF YOU REQUIRE AN ALTERNATIVE FONT FOR YOUR PRESENTATION, PLEASE EMBED THAT FONT IN YOUR PRESENTATION.



THIS SLIDE CONTAINS OLE OBJECTS AND CAUSES EMBEDDING OF THE RESPECTIVE OLE SERVERS IN THE TEMPLATE.

LEAVE THIS SLIDE AT THE VERY END OF THE PRESENTATION WHICH SHOULD FORCE THE OLE SERVERS TO REMAIN EMBEDDED IN YOUR PRESENTATION.

PLEASE EMBED ANY ADDITIONAL OLE SERVERS YOUR PRESENTATION MAY REQUIRE.

Spectrum Analyzer Labs (ESA/PSA) 7/26/06

EXERCISE 1

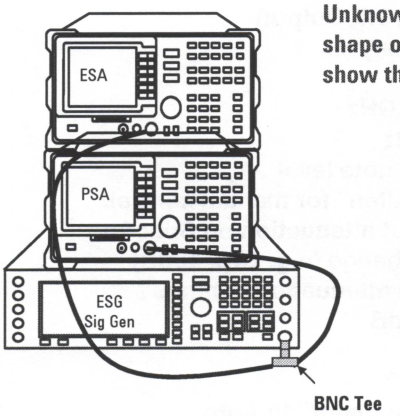
Front Panel Operation

1. **Locate Frequency, Span, and Amplitude [Hardkeys]**
2. **Locate (Softkeys) on right side of screen**
3. **Notice how (Softkey) menu changes when different [Hardkeys] are pressed**
4. **Input a 2.5 GHz, -10dBm signal and locate it using the Frequency, Span and Amplitude [Hardkeys]**
5. **Optimize REF Level, Span, RBW and VBW**

Each Spectrum Analyzer [Hardkey] is a physical button on the front panel of the instrument. (Softkey) menus appear vertically along the right side of the display panel and change with each [Hardkey] that is pressed. When more (Softkeys) than can fit on one screen are available, pressing "more" or "2 of 3" will advance to the next screen of (Softkeys). "Return" will set the (Softkey) menu back to its previous state.

EXERCISE 2

RBW Filter, Selectivity, Shape, Filter Type, Filter Selectivity



Unknown signal – Show the signal tracing out the shape of the RBW filter. Reduce the filter BW to show the effects of filter type and filter selectivity.

EXERCISE 3

Input Attenuator

1. **Preset Source**
2. **Press "Frequency" and set for 2GHz**
3. **Press "Amplitude" and set for -10dBm**
4. **Press "RF On/Off" to "On" (Near RF Output)**
5. **Connect Source to Spectrum Analyzer**
6. **Preset Spectrum Analyzer**
7. **Press "Frequency" and set for 2GHz**
8. **Press "Span" and set for 100MHz**
9. **Press "Maker Peak Search" and note level**
10. **Press "Amplitude" and press "Atten" for manual control.**
11. **Use "Up Arrow" to Increase input attenuation on SpecAn**
12. **How much did the attenuation change (e.g. 2dB, 10dB)**
13. **Is the signal level changing with attenuation settings?**
14. **Increase input attenuation to 30dB**
15. **Did the input level change?**
16. **What happens to the noise floor?**
17. **Press "Amplitude" and set "Attenuator" to Auto.**
18. **What happens?**

Input Attenuator:

The RF input attenuator is used to adjust the level of the RF signal into the mixer. It is important to be able to do this in order to protect the mixer from large signals and to control the spurious free dynamic range of the spectrum analyzer. The RF attenuator may be set to zero dB, however this condition must be used with care, analyzer designers have used mechanical interlocks or special button sequences to avoid an operator accidentally selecting 0dB attenuation. Most analyzers have attenuators with the range 0dB to 70dB with ten or five dB step selection.

Input Filter:

This limits the amount of RF energy to the band of the analyzer. In an RF analyzer this band is the whole RF bandwidth of the instrument. In a microwave spectrum analyzer (for example > 3GHz) this filter is a tunable bandpass filter which tunes with the sweep, called a *microwave preselector*.

EXERCISE 4

IF also called RBW (Resolution Bandwidth) Filter

1. **Press "FM" key on source**
2. **Turn "FM On" using soft key**
3. **Set "FM Dev" to 1kHz**
4. **Set "FM Rate" to 10kHz**
5. **Connect Source to Spectrum Analyzer**
6. **Preset Spectrum Analyzer**
7. **Press "Frequency" and set for 2GHz**
8. **Press "Span" and set for 100MHz**
9. **Press "Maker Peak Search" and note level**
10. **How many signals are present?**
11. **Press "Span" key and record current span**
12. **Record current RBW (Bottom left of display)**
13. **Use "Down Arrow" once to decrease the Span and note the span and RBW**
14. **Use "Down Arrow" again and note the span and RBW**
15. **Use "Down Arrow" again and note the span and RBW. Is there a pattern?**
16. **Continue to decrease the span to 100kHz and record how many signals are present?**
17. **What is the RBW?**
18. **Why can we see more signals now?**

The Intermediate Frequency (IF) or Resolution Bandwidth (RBW) Filter:

The IF filter is also known as the Resolution bandwidth filter. When you change the RBW on the analyzer, you change the bandpass width of this filter.

The IF filter is a bandpass filter that is used as the "window" for detecting signals.
Spectrum analyzers typically give several choices of RBW settings. By having a broad range of variable RBW settings, the analyzer can be optimized for a given measurement condition.

The example in this illustration shows that as the filter is narrowed, selectivity is improved and two closely spaced input signals may be resolved. This will, however, slow down the sweep speed.

The resolution bandwidth filter will be discussed in other parts of this class.

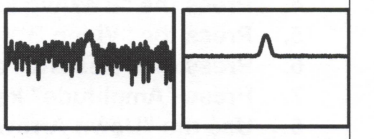
EXERCISE 5

RBW Filter Shape

1. **Preset Spectrum Analyzer**
2. **Press "Frequency" and set for 2GHz**
3. **Press "Span" and set for 20MHz**
4. **Press "BW/Avg" key**
5. **Press "Res BW" Soft Key and change to "Man"**
6. **Note the signal on the display and the RBW setting**
7. **Use "Up Arrow" once to increase the RBW and display and RBW**
8. **Use "Up Arrow" again and note the display and RBW**
9. **Use "Up Arrow" again and note the display and RBW**
10. **What does the shape of the signal on the display change?**

EXERCISE 6

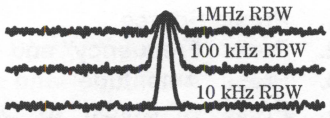
VBW (Video Bandwidth) and Noise



1. **Preset Source**
2. **Press "Frequency" and set for 2GHz**
3. **Press "Amplitude" and set for -75dBm**
4. **Press "RF On/Off" to "On" (Near RF Output)**
5. **Connect Source to Spectrum Analyzer**
6. **Preset Spectrum Analyzer**
7. **Press "Frequency" and set for 2GHz**
8. **Press "Span" and set for 20MHz**
9. **Press "Maker Peak Search" and note level**
10. **Press "BW/Avg" key and Press "Video BW" to select "Man"**
11. **Note the signal display, RBW and VBW settings.**
12. **Use the "Down Arrow" to decrease VBW one setting and note signal display.**
13. **What happens to the noise and signal?**
14. **Use the "Down Arrow" again and note the signal and noise levels.**
15. **What happens when the VBW is decreased to 100Hz?**

EXERCISE 7

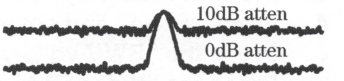
RBW and Noise



1. **Preset Spectrum Analyzer**
2. **Press "Frequency" and set for 2GHz**
3. **Press "Span" and set for 20MHz**
4. **Press the "BW/Avg key**
5. **Press the "Video BW key and set to 200Hz**
6. **Press the "Res BW" and set to 1MHz**
7. **Press "Amplitude" key and select "Ref Lev"**
8. **Use the "Down Arrow" and tuning know to position the noise trace to the middle of the display**
9. **Press the "Trace/View key and press "View"**
10. **Press "Trace" soft key and select trace 2**
11. **Press "Clear Write"**
12. **Press "BW/Avg" key and note the RBW.**
13. **Press "Res BW" Soft Key and set to change to "Man" and enter 100kHz.**
14. **Note the display. How far did the Noise drop? How much did the RBW change?**
15. **Press "Trace/View" key and press View**
16. **Press the "Trace" soft key and and select trace 3. Then press "Clear Write"**
17. **Press the "BW/Avg" key and set Res BW to 10kHz.**
18. **Note the display. How far did the Noise drop? How much did the RBW change?**

EXERCISE 8

Sensitivity and Input Attenuation



1. **Preset Spectrum Analyzer**
2. **Press "Frequency" and set for 2GHz**
3. **Press "Span" and set for 20MHz**
4. **Press the "BW/Avg key**
5. **Press the "Video BW key and set to 200Hz**
6. **Press the "Res BW" and set to 1MHz**
7. **Press "Amplitude" key and select "Ref Lev"**
8. **Use the "Down Arrow" and tuning know to position the noise trace to the middle of the display**
9. **Press "Trace/View key and press "View"**
10. **Press "Trace" soft key and select trace 2**
11. **Press "Clear Write" note level of input atten and noise floor.**
12. **Press "Amplitude" key and set "Attenuation" to 0dB**
13. **Note the level of the Atten and noise floor. How far did the noise floor drop? How much input attenuation was removed?**

EXERCISE 9 -Detection Modes

1. **Press "RF On/Off" ket to Off (Next to RF output connector)**
2. **Preset Spectrum Analyzer**
3. **Press "Frequency" and set for 2GHz**
4. **Press "Span" and set for 20MHz**
5. **Press the "BW/Avg key**
6. **Press the "Video BW key and set to 200Hz**
7. **Press the "Res BW" and set to 1MHz**
8. **Press "Amplitude" key and select "Ref Lev"**
9. **Use the "Down Arrow" and tuning know to position the noise trace to the top of the display**
10. **Press Amplitude and "Scale/Div" and set to 2dB**
11. **Press Det/Demod and set to "Peak"**
12. **Press "Trace/View key and press "View"**
13. **Press "Trace" soft key and select trace 2**
14. **Press "Clear Write" note level of Noise.**
15. **Press Det/Demod and set to "Negative Peak"**
16. **Press "Trace/View key and press "View"**
17. **Press "Trace" soft key and select trace 3**
18. **Press "Clear Write"**
19. **Press "Det/Demod" and select "Sample"**
20. **Note impact of Detector on noise levels**

EXERCISE 10

Zero Span (Amplitude vs Time)

1. **Press "RF On/Off on source to "ON" and set amplitude to -10dBm**
2. **Press "AM" key and turn AM "On"**
3. **Press AM Depth and set to 20%**
4. **Press AM Rate and set to 10kHz**
5. **Preset Spectrum Analyzer**
6. **Press "Frequency" and set for 2GHz**
7. **Press "Span" and set for "Zero Hz"**
8. **Press "Amplitude" key and select "Scale Type" Lin**
9. **Press "Ref Level" and adjust to top of display**
10. **Press "Sweep" key and set sweep time to 1ms**
11. **Press "Trigger" key and set to "Video" and adjust green line to the middle of the sine wave.**
12. **Press "Marker" key and adjust to peak.**
13. **Press "Delta soft key and move to next peak.**
14. **Note the time difference and compute the frequency**
15. **Press more 1 of 2 key and select "Readout" and Inverse Time**
16. **Note the frequency on the display. Is this the same as your calculation?**
17. **Why is there a sine wave present?**
18. **Is this AM or FM modulation?**
19. **Would FM modulation show in Zero Span? Why?**

EXERCISE 11

Frequency Accuracy

1. **Press "RF On/Off on source to "ON" and set amplitude to -10dBm**
2. **Press "AM" key and turn AM "Off"**
3. **Preset Spectrum Analyzer**
4. **Press marker "Peak Search" key**
5. **Note the frequency. What is the difference compared to the source?**
6. **Press "Marker >" key and press Marker > CF**
7. **Press marker "Peak Search" key**
8. **Note the frequency is this closer to the source?**
9. **For PSA - Press the "Marker Fctn" key and select "Marker Count" and "Marker Count On"**
   For ESA – Press "Freq Count" Hardkey. Select the Marker Count (On) softkey
10. **Note the difference between the Marker and Counter readouts (Counter readout at top of display)**

EXERCISE 12

RBW and Measurement Time

1. **Press "RF On/Off on source to "ON" and set amplitude to -10dBm**
2. **Preset Spectrum Analyzer**
3. **Press "Frequency" and set to 2GHz**
4. **Press "Span" and set for100kHz**
5. **Press the "BW/Avg key**
6. **Press the "Res BW" and set to 1kHz**
7. **Press the "Sweep" key and select "Sweep Time Man"**
8. **Note the signal amplitude**
9. **Use the "Down Arrow" to decrease sweep time to 5ms**
10. **What happens to the amplitude? Why?**

EXERCISE 13

Distortion (Attenuator Test)

1. **Press "RF On/Off on source to "ON" and set amplitude to +4dBm**
2. **Preset Spectrum Analyzer**
3. **Press "Frequency" and set to 2GHz**
4. **Press "Span" and set for 1MHz**
5. **Note the two tone spur levels using markers.**
6. **Press the "Amplitude Key" and set Attenuation to Man**
7. **Use the Up arrows to increase the step atten and note the spur levels. What happens when the atten is increased?**
8. **If the spurs decrease with increasing atten is the distortion from the spectrum analyzer or source?**

EXERCISE 14

Channel Power (Noise like Signals)

1. **Press "RF On/Off on source to "Off"**
2. **Preset Spectrum Analyzer**
3. **Press "Frequency" and set to 2GHz**
4. **Press "Span" and set for 1MHz**
5. **Press "Amplitude" and "Ref Level" adjust to top of display**
6. **Press "Marker" to turn on a marker and note the level.**
7. **Press "BW/Avg" key and decrease the RBW once with the down arrows.**
8. **What happened to the power measurement? Did it go up or down? Why?**
9. **Press "Marker Fctn" and select Band/Intvl Power**
10. **Press "Marker" key and select "Ref" to position the Ref location.**
11. **Press "Delta" to position the delta location.**
12. **What is the analyzer measuring?**

EXERCISE 15

Spurious Measurements

1. **Press "RF On/Off on source to "On"**
2. **Set Source Frequency to 1GHz**
3. **Set Source Amplitude to +5dBm**
4. **Preset Spectrum Analyzer**
5. **Press "Frequency" and Start freq to 800MHz and stop freq to 3.5GHz**
6. **Press "BW/Avg and set RBW to 30kHz and VBW to 30kHz**
7. **Note the signals and their levels.**
8. **How are these signals related to each other?**